COAL WASHING

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THIS BOOK IS DEDICATED
TO THE MEMORY OF
THE LATE
ELLWOOD A. STEWART
IN RECOGNITION OF HIS COURAGEOUS
PERSISTENCE AND ENGINEERING
SKILL IN THE DEVELOPMENT
OF THE ART OF COAL
WASHING

PREFACE

This book has been compiled for the purpose of giving a systematic description of modern practice in the art of coal washing. This may appear at first glance to be much easier than it really was. The question arose: Should preference be given to the methods at present in actual use or to those which in the light of our present experience are most judicious?

There will be always a difference between ideal performance and what is actually accomplished. A coal washery is an expensive installation, built for long service. During its useful life the art of coal washing may advance uninterruptedly. The necessary and justifiable desire of the operator to try out all useful inventions, tends in some degree to equalize the above difference. New apparatus can be added to an old washery, but the total reconstruction of an existing plant, so as to bring it up to modern practice, is hardly justified, since on account of the constant changes in our ideas and the development of new machinery, the remodeling of a plant would never be finished.

To neglect in this description the older types of washeries, which are still in operation and doing good work, would put the present and future into too prominent a place.

This book is intended to furnish the coal operator with the necessary knowledge whereby he may distinguish in washeries between the modern and earlier apparatus and methods which may be working side by side.

Everything is omitted concerning apparatus which because of a lack of progressive spirit is still in use, even though it be archaic. Only a study of the chronological development of the art of coal washing will enable us to make a judicious selection of equipment.

An effort is here made to set up a proper or standard rule for guidance in the present as well as the future, from a survey of the experience of the past, with its mistakes and blind alleys, its roundabout ways and unwarranted short-cuts. Only such methods will be omitted as have been proven impracticable and useless.

It must be remembered, however, in connection with the above statement, that a good many failures during the earlier stages of the development of coal washing were caused by the lack of proper technical training and education on the part of the experimenters. No failure of a method during the earlier periods of coal washing can be considered as being complete either at present or in the future.

The present state of coal washing is the result of a steady evolution. A comprehensive description of the development of this art must be based upon its chronology. Therefore in the first part of this book the attempt is made to show the march of progress and to mention some of the failures. The second and main portion of the book is closely allied to the historical division. It was necessary to make this separation so as not to encumber the second part with a tiresome historical review. A judicious selection was required for the description of the historical evolution. The purpose and scope of this book does not permit an exhaustive chronological summary.

The main object of this work is treated in the second part. Therefore only the most important lines of evolution are given. These embrace those trends or influences which partly enter into present practice and partly on account of the obvious failures permit the young inventor to exercise his genius for the discovery of more useful and promising methods.

In preparing this book I have been about equally author and compiler, since I have extracted quite half of its contents from the works of the best writers and metallurgists. Perhaps it would have been better and more acceptable if I had extracted more and written less.

Still, possibly half is my own, and in incorporating here the thoughts and words of others I have continually changed and added to their language, often intermingling in the same sentence my own words with theirs. This book being intended for the technical fraternity, I have felt at liberty to make from all sources a Compendium of Coal Washing; to remold sentences; to change the words and phrases, combining them with my own and using them as if they were my own, to be dealt with at my pleasure and so employed as to make the complete work most valuable for the purpose intended.

I claim, therefore, little merit of authorship and have not

cared to distinguish my own language from that which I have taken from other sources, being quite willing that every portion of this book, in turn, may be regarded as borrowed from some more skilful author.

Finally, it may be said that this book is at present the only work which deals with the subject of coal washing exclusively. And while this volume does not do this exhaustively and does not claim to do so, it is hoped that it presents in a convenient form the information sought by coal operators, students and all those who are interested in the art of washing coal.

In many places in these pages I have tried to give credit to the many friends who have rendered me assistance in divers ways. Especially I am under obligation to the director of the Bureau of Mines and the director of the Engineering Experiment Station of the University of Illinois for their permission to reprint part of their publications. It only remains to thank them as a whole for aiding in this work which has been accomplished in the intervals of what I trust is not otherwise an entirely idle and useless life.

Ernst Prochaska, M.E.

Bonne Terre, Missouri,
November, 1920.

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PART I

THE DEVELOPMENT OF COAL WASHING

CHAPTER I

THE PURPOSE AND THE VALUE OF WASHING COAL

The existence of every coal mine depends solely upon the selling price of its product exceeding the cost of production. It may be feasible to operate a washery or a screening plant in connection with a coal mine if the better price obtained for the cleaner coal equals the cost of operation; or these plants may be operated at a loss, if thereby part of the mine output can be made salable or its sales increased.

Under the last named conditions, however, the preparation plant is only a necessary evil installed to satisfy the consumers The management will be inclined therefore to make this plant as small and as simple as possible. If, however, the difference between the selling prices of raw coal and prepared coal is greater than the cost of preparation, the preparation equipment is co-operating with the mine to get a bigger profit for the whole mining plant; and the management will energetically use every effort to improve the method of preparation, to increase the difference between cost and selling price by decreasing the cost of preparation and by producing a high-grade prepared coal.

The foregoing facts are now well known, but it took a long time before the coal industry was fully convinced of their truth. The first preparation plants were not installed for the purpose of increasing the profits of a mine but were forced upon the coal industry by the demands of the consumers for a better product.

The first demands for cleaner coal were made by the blast-furnace men who wanted a coke with less ash. This demand for a cleaner coal was restricted to comparatively few localities, and it was only after it had been thoroughly demonstrated that the greatest benefit accruing from coal preparation lay in the possibility of increasing the value of the coal and thereby the selling price far above the cost of preparation, that the coal industry took hold of this problem.

Coal operators in the beginning felt little interest in this problem of producing cleaner coal and only those mines shipping coal to blast furnaces and railroads took any interest in it at all. The reason for this attitude can be found in the view taken in regard to the purpose of coal washing, which a French engineer "Marsilly" expressed as follows: "The purpose of coal washing is: to get a price for the washed coal equal to the market price of the raw coal plus the cost of washing." Any other possible motive was at that time not taken into consideration.

It will be readily appreciated that such an opinion did not encourage a vigorous development of coal washing. The ruling aim was, not to decrease the economical results, obtained in the past without washing, by the introduction of this process. The same thoughts can be noticed in all publications during the first decades of coal washing.

Not until the year 1864 did Gaetzschmann break through this narrow view. He stated that the main value of coal washing lies in the increase of the selling price over and above the cost of washing. This progressive view however did not find general recognition. A conservative attitude on the part of the industry condemned his views for almost 20 years.

In the year 1865 Fleck declares again, that the cost of washing should not bring about an economical disadvantage. The lack of interest shown by the coal operators in coal washing forces Pernolet in the year 1873 to complain that the purchaser is compelled to take the screenings as they come from the mine. An almost complete resignation to existing régime is expressed in the following: If the coal mining company is not at the same time interested in coke making, it does not happen often that screenings are suitably adapted for making coke. The coke maker must therefore take what the market rejects.

In a similar manner Nonne in 1876 reviews the conditions in Westphalia. With the exception of the mines which are forced by extremely dirty coal or by special market conditions, to wash the coal, all other mines have always considered a washer as an expensive and troublesome appendix which should be avoided by all means. Nonne replied to this by proving that the value of coal increases faster than the ash contents decrease. At this time his warning was very appropriate, because on account of the existing boom times, the best coal was frequently, either purposely or by accident, mixed by the miners as well as the loaders with slate, rock and bugdust, because being pushed from all sides, there was no time for a proper preparation.

Besides the visible advantage of a larger profit, the economic question of the fuel supply commenced to be understood. It was plainly visible that a properly functioning separation plant could permit the mining of a coal bed, the coal from which on account of its large percentage of impurities could not be sold in the raw state.

Only after a full realization of the truth of the above statement did the process of coal washing enter upon that period of development which took into account the importance of this process and permitted the utilization of all its advantages to the fullest extent.

Even as late as in the year 1918 Thomas James Drakeley states that washing is regarded as a troublesome and expensive operation at most collieries and that only once in his experience was unqualified satisfaction expressed with regard to a washer.

The endeavors of a good many inventors however outstripped the practical views of the industry and in some instances overshot their scope. Enthusiastic inventors full of hope forgot, in their eagerness to clean the coal, the cost of performing this operation and also the necessary simplicity and efficiency of the apparatus to be employed. Consequently a good many devices appeared which were sufficiently complicated for the concentration of even complex ores, but which were neither useful nor necessary for the washing of coal.

There were plenty of failures and it must in justice be said that such failures have been responsible in many cases for the unfavorable opinion in regard to the washing of coal. A good

many coal washers built as late as the seventies of the last century were abandoned and dismantled.

After about 70 years of evolution however a fairly clear appreciation of the advantages and limitations of this method of coal preparation has been reached. After the resistance of operators against washing had been finally overcome and their first eagerness modified, practical experience came forward as a splendid teacher. This experience is at present sufficiently developed to confute any dogmatic unfavorable opinion in regard to coal washing and to establish the following maxims:

1. The preparation of coal shall, by the cleaning of the raw material and the production of suitable and well screened sizes, secure a maximum price per ton of output.

2. To arrive at this result three points must be kept in view: (a) Highest possible purity of coal; (b) smallest possible loss of coal; (c) small cost of production.

3. As the foregoing three demands are conflicting, it will be necessary for the proper and economical installation of a preparation plant to find in each case the best relation between the three factors.

CHAPTER II

DEVELOPMENT OF THE PREPARATION OF COAL

General. Only by consulting the technical journals is it possible to follow the development of the preparation of coal to its very beginning. Any description of this development necessarily will be incomplete as not all experiments found their way into print. During the earlier periods means of communication were not plentiful and authors were compelled to restrict their investigations within quite limited zones. This also explains the fact that the development of coal preparation showed at corresponding periods a very different degree of advancement in different localities. While in one district the mechanically operated and continuously working jig was the accepted apparatus, other districts were still using hand actuated jigs. Crude screening plants with wicker work screening surfaces are contemporary with conical revolving screens with mantles made of perforated iron plates.

Only from the time when international industrial exhibitions were held in different countries onward can a uniform development of methods and apparatus be noticed. The exhibitions also brought about a quicker advancement on account of the avoidance of mistakes, which were quickly recognized through the exchange of views between the different districts.

The same division will be used in the description of the historical development as is employed in the second portion of this book, so as to facilitate the reference from one part to the other.

Methods used in the Mine. The maxim of loading the coal as clean as possible has been known and practiced to a greater or less extent since coal has been mined. As early as the first quarter of the last century slate was picked out of the coal in the mine and gobbed. But in the earlier periods this practice of hoisting only clean coal was carried still farther and the coal operators tried, following the example given by the ore miners,

to carry on the preparation of coal within the mine itself. The most widely used method was that of loading only lump coal by using forks with tines spaced at a certain interval. To separate the coal into different sizes was also attempted. This was carried on with especial care in some mines in Saxony.

After the coal was shot down, the floor of the room was carefully brushed off and the screened coal deposited on the floor in three or four heaps, according to their respective sizes. Such methods, however, could not prevail for long. With the increase in tonnage produced and the advance in labor cost, the amount of coal mined per man was of greater influence than the quality of the coal. The system of paying the miner only for the lump coal could only be applied at mines where the market price for lump was much higher than that for mine-run.

Generally speaking, a strict inspection combined with a just docking system and the avoidance of breaking the coal on its way through the tipple, are the only means employed at the present time to secure the loading of a clean, well sized product.

Dry Separation. Dry separation is usually accomplished with screens and the methods of screening can be separated into two groups: The first deals with screens for the purpose of making lump coal and screenings only; the second deals with screens that classify the product into lump, egg, nut and different sizes of screenings. The first group belongs solely to the dry separation process, whereas the second group belongs to it only if all the coal is prepared in a dry state. If a washery is connected with the mine the classification screens belong properly to the washing plant.

Mechanical Preparation of the Screened Coal. At present the preparation of the screenings is carried on with water and is mostly done in jigs. In the beginning, however, many processes were devised to avoid the use of water and even now many inventors are working on the solution of other separation processes, which will take the place of wet separation. New devices and apparatus are constantly appearing and it seems therefore judicious to enter more in detail into the past history. By this means many ideas which at present are considered novel will be found to be only returns to a circuitous path of development. The wet separation always has had a decided advantage. Be-

fore we enter into the description of this process, however, we must consider the development of the classification of fine coal. Two different opinions in regard to the proper way of carrying on screening have always existed: (1) Screening from coarse to fine and (2) screening from fine to coarse. There also exists the question of whether it is better to screen before washing or to wash first and then screen.

In the beginning screening from fine to coarse was preferred. It was the shortest method and had the advantage that the dust was removed on the first screen plate, or that having the smallest perforations. But it had the drawback that the fine screens wore out quickly on account of the large mass of coal passing over them, and furthermore this large mass of big coal did not permit perfect screening. Both these disadvantages became greater as the quantities to be handled increased. In the sixties of the last century the practice reversed itself completely and most screening was done with concentric revolving screens. This method, however, did not remain long in actual practice. The demand was for a method of screening that would give output, durability and simplicity combined. These three demands were fulfilled by the shaking screen and later by the vibrating screen.

The importance attaching to the order in which the different sizes are screened off slowly disappeared and in its place arose the following questions: Which arrangement of screening apparatus will best fit into the general layout and permit the best possible use of the space at disposal? Furthermore, which will permit the simplest and most economical conveying of the different sizes to the next following piece of apparatus? More or less freedom in all dimensions of a contemplated screening plant is at present the deciding factor and as the different types of screens vary much in their dimensions, we encounter not only the most extreme types but also a great many variations combining different types in one plant. Of course, if sufficient room is available, the screening plant will be adapted in each separate case to the physical condition of the coal. Important for the present consideration is the fact that the development of practical experience has robbed the question of coal classification preparatory to washing of its fundamental importance.

As long as jigging was performed on hand jigs nobody thought

about classifying the coal. This, however, was not because the operator was convinced of the correctness of his method, but because at that time only the simplest and cheapest pieces of apparatus were used. Later on, after the jigs were improved, it was found that the separation was not particularly close and lack of sizing was blamed therefor. Since in ore dressing plants close classification was considered necessary, this was followed also in the coal washeries.

At first this was carried too far, and even the fine coal was divided into three or four sizes. But later on it was found that this close sizing produced too tight a bed in the jigs and it became necessary to mix in some nut coal. Nevertheless sizing apparatus remained a part of the equipment of every washery. The screening of the coal, however, was troublesome and made the washery complicated.

Close classification (except in the case of very small sizes) was in use until the end of the seventies. It was not, however, proved to be correct either by theoretical investigations or by practical comparative tests. In the beginning of the eighties the opinion in regard to classification changed slowly. It was remembered, that it is possible to separate in a jig, materials containing grains of different diameter. It was also discovered that the specific gravity of the materials encountered was favorable for jigging. In the year 1878, when Althans published his review of the status of coal washing, jigs for classified and unclassified coal were used indiscriminately side by side.

Every effort was now made in classifying plants to simplify the total arrangement of the coal washery. Althans describes the prevailing views in regard to this as follows: If previously the theoretical efforts towards an improvement in coal washing were carried too far and resulted in the arrangement of complicated installations, we find in the newer plants, even, where the most perfect apparatus is used, preference shown to comparatively simple methods. Artois also notes that the compromise in regard to classification of coal to be washed remained in vogue for several years. Later on, however, more attention was paid to a minute classification before washing. A great number of washeries which were described in the technical journals of that period are proof of the changed views on this subject. A return

to the former views was partly brought about because the reasons given for the other methods were not properly or at least not exhaustively stated. It was a great mistake to use these views as a guide in all cases.

In 1890 Remy points out that the nature of the raw coal must be considered in each separate case in order to decide intelligently on the proper type of classification method. Even at present we have no absolute convincing answer to the problem of the best procedure to follow.

Remy's statement describes the situation correctly. Both systems were used side by side, but the classification before washing had the preference. There was little reason to change this method, because the market demanded a great number of different sizes. It is, however, of interest to note that this demand caused the first break in the method of classifying before washing. The sharper competition and the increased demands of the consumers called for exact screening and with the beginning of this century it was found advisable to limit the classification before washing, because a classification after washing prevented considerable abrasion and permitted the loading of a perfectly screened coal.

In adherence to the previous methods, a classification into two or three sizes was still prevalent. All the washed coal, however, was re-united after washing and finally screened into the market grades. The latest step was taken by Baum in Europe and Stewart in America, who used the slogan: *First washing—then screening.* Large jigs were introduced, taking all screenings from 3 in. down. But even this simple method is again surpassed by the more modern system of using separate jigs or concentrating tables for coal smaller than 5/16 or 3/8 in. This method is, however, only in its infancy and a great majority of American washeries are handling unscreened coal from 3 in. down or if the coal is to be used for coke making from 1 in. down.

The choice of the proper method to be pursued in coal washing is an extremely difficult matter. It frequently happens that a method effective at one mine will not produce the desired results if it is adopted in its entirety at another. At each mine there are peculiarities which demand special treatment.

The deciding factor in the selection of a suitable washer

should be the physical and chemical characteristics of the raw coal. It is only by expending much thought on the problem of selection that disappointments may be prevented.

Coal washing is rapidly coming into its own and before many years as careful attention will be given to the design and construction of coal washeries as is now being expended upon by-product plants and other allied industries. Heretofore, coal washing has been considered only as an incidental and a necessary evil instead of the big problem it really is—one worthy of the most careful study by men well trained along technical lines and capable of delving into the fundamental principles.

The knowledge gained by past experience can be condensed into the following paragraphs:

The jigging of bituminous coal can be carried on successfully without preparatory sizing.

Experience has shown that the separate washing of the fines facilitates the washing process and gives slightly better results. It has been proved, however, that coal finer than 10 mesh can not be improved by washing and should, if low enough in ash, be mixed with the washed coal; or if too high in ash used for other purposes.

The advisability of sizing the larger pieces of coal before washing must be judged for each installation separately.

To produce a perfectly sized washed coal screening after washing is necessary.

The whole question, where favorable raw coal is involved, is not of decided importance. It must be determined in most cases by considering the cost of installation and operation, the space required and at disposal, and the most suitable general arrangement of the plant.

CHAPTER III

CRUSHING

General. A crushing plant must in many cases be added to the preparatory apparatus of a coal washery. The crushing is either for the purpose of separating the pure coal from the slate and pyrites, or producing a coal of suitable size.

The proper design of the first crushing plants suffered, as did all the other units of a coal washery, through the lack of proper research studies carried on by technically trained men. The fact that coal should be crushed without producing too much fines and dust was known in the year 1840 by the anthracite coal operators of Pennsylvania. Berard transmitted this knowledge to Europe in 1850. But that all precautions must be taken to restrict the crushing to its proper sphere was only recognized in the eighties, when attention was paid to the handling of middle products.

In the case of coking coal it was always the prevailing idea to crush as fine as possible. This did not take into consideration that thereby the slate is pulverized to the same degree as the coal, which causes trouble in the jigs and makes the washing difficult. The following statements show how little proper crushing was understood at that time.

Meynier in 1857 says: "If coal of different sizes must be washed it is advisable to disintegrate it in order to facilitate the washing, especially if the coal contains laminated flakes of pyrites and slate." Further on he states: "To separate the slate it is advisable that the coal is reduced to fine dust. As the slate is mostly attached to the coal in thin slivers, it breaks off by crushing and can be separated without great loss."

To the contrary Gaetzschmann in his textbook published in 1864 says:

"The crushing of coal is only advisable in certain, rare cases, and there is no reason for the crushing plan to be an essential part of every coal

washery. A suitable classification will make the crushing rolls superfluous. The crushing of coal has not always, as is sometimes supposed, the effect of separating the slate from the coal, because with some coal the adhesion of slate to the coal is greater than that of the coal particles to each other."

David Hancock in one of his reports on a contemplated washery says: "If you could crush the coal without crushing the impurities, I would say that a size smaller than $\frac{3}{4}$ in. would be profitable, but the trouble is that you are going to crush the slate as well, and instead of having 8.4 per cent. of stuff finer than 20 mesh running 10.90 per cent. ash, you are going to get about 16 per cent. running in ash up to or near the raw coal or about 18.0 per cent.

The almost general use of crushers in Gaetzschmann's time can be explained by the fact that at that period the major portion of the fine coal was lost and wasted on the refuse dump. This loss of fine coal reduced the amount of a size needed for coke making to such an extent that some of the coarser coal had to be crushed.

By using better methods of washing the finer coals, this extra supply of fine material was no longer needed and it was possible to restrict the crushing. In the eighties a start was made to separate the slate disseminated throughout the coal on a picking belt or in jigs and to crush only the middle product containing slate intimately mixed with the coal.

After cognizance had been taken of the bad results obtained from crushing before washing, the methods employed developed in such a way that coal was crushed after washing and the crushing was restricted to the middle products only. At present we can adopt for this method the slogan: *"First Washing—Then Crushing."*

Some washeries go so far at present as to rewash the middle products, without crushing, for the purpose of separating the pure slate and to prevent it from being crushed. The description of the difficulties encountered in the clarification of the wash water will show that there is some well-founded reason for using such a method.

During the last ten years more attention has been paid to the crushing of lump coal into smaller sizes. At least one mine in Illinois is crushing the whole output. The general use of mechanical stokers and the manufacture of gas calls for nut coal

and screenings, so that in some districts the price of nut coal has advanced over that of lump.

The modern requirements for a crushing plant are as follows:

1. Crushing lump coal to nut, avoiding thereby as much as possible the making of fines and dust.
2. Crushing the middle products, for the purpose of separating the adhering slate and pyrite.
3. Crushing and mixing different coals to be used for coke making.

Crushing Apparatus. As early as 1840 roll crushers were used in Pennsylvania to crush lump coal down to nut. Berard

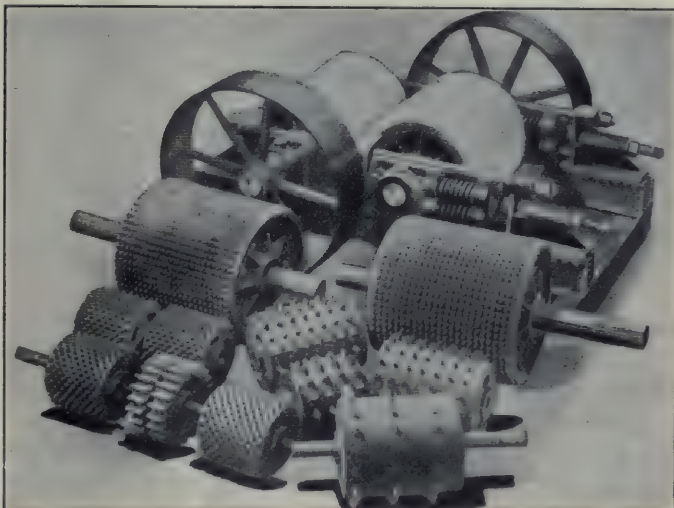


Fig. 1. Different Types of Rolls used for Crushing Coal

introduced this type of crusher into Europe, where it is still in use, together with gyratory crushers while even pug and ball mills have been used. In the year 1870 Carr introduced in England a disintegrator similar in design to the Stedman disintegrator used in America. Jaw crushers for coal were used in the eighties in Europe and at present a great variety of crushers are there employed. Jaw crushers were modified into needle crushers, to prevent the making of too much fines.

Roll crushers have either smooth, corrugated or toothed rolls. Disintegrators are mostly used to pulverize and mix coal to be

used for coke making. In America roll crushers with either corrugated or toothed rolls are the accepted standard type. Toothed rolls are used for the preliminary breaking of the lump and the corrugated rolls for the final crushing. Fig. 1 shows a variety of rolls and Fig. 2 gives a good illustration of a large

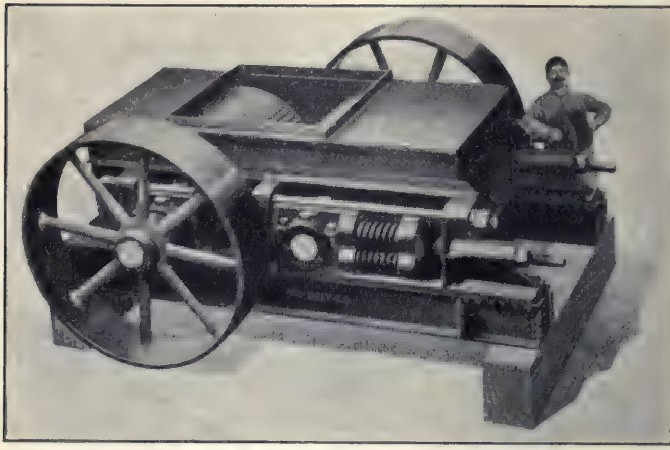


Fig. 2. Belt-driven Coal Crusher

belt driven crusher, having a maximum capacity of 1,000 tons of coal per hour.

In selecting a crusher it is advisable in each separate case to choose a machine adapted to the characteristics of the coal and to combine the quantitative and qualitative capacity so far as possible with a simple and rugged construction.

CHAPTER IV

DEVELOPMENT AND THEORY OF WET SEPARATION

Wet separation has been and is still the fundamental operation in coal washing and the genius of inventors has been principally exercised to improve this process. The theoretical principles of "wet mechanical separation" were well developed and were followed to a great extent in ore dressing, at the time the first timid experiments were made in coal washing. Consequently coal washing followed in the footsteps of ore dressing and the following theory of jigging, even if dealing with metalliferous materials, can be adapted with slight changes to coal washing.

The Process of Jigging. Jigs are usually built in the shape of a tank, divided into two compartments by a partition. This partition is not carried quite to the bottom of the tank, so that the two compartments are intercommunicating. In one of the compartments a screen is securely fastened, somewhat below the top edge of the tank in a horizontal or slightly inclined position. In the other compartment, a plunger can be moved up and down by mechanical means.

The tank is filled with water to such a height that the screen and the superimposed bed of material to be treated is always submerged.

The material to be jigged is spread out over the screen, while the plunger is in motion. On the down stroke of the plunger the water flows from the plunger compartment into the screen compartment and through the perforations of the screen. This action lifts the bed off the screen. At the up stroke of the plunger the water recedes and the bed drops back upon the screen. By this means the particles of the bed become stratified in such a way that the denser particles collect upon the screen, whereas the lighter ones will be pushed to the top of the bed. By repeating this plunger motion, a complete separation of the

different particles according to their specific gravities can be accomplished, provided the difference in the specific gravities of the separate particles is well defined and the jig is properly designed and operated.

This fact has been known for a long time and applied in actual practice. But no entirely satisfactorily theoretical explanation has been given to show clearly how and why this separation takes place.

Linkenbach takes the stand that classified grains, i. e., materials collected by screening into a group or groups of approximately the same size, are separated in a jig according to the law of *equal settling.* He says that the specifically lighter grains are lifted higher than the denser ones and that the lighter particles do not drop back quite so far as the denser ones; so that by repeating the plunger motion, the distance between the lighter and the denser grains will become greater and greater. He considers that the separation of a screened product in a jig is similar to classification.

Bilharz states that the *equal settling* qualities of solid grains are important means for the separation of pieces of different specific gravities, whose diameter, however, are in a certain proportion to one another, either in a quiet body of water or still more effectively in an ascending column of water. He furthermore states that if the material to be treated contains several different substances the separation takes place in an intermittently ascending column of water. This upward movement of the water can be produced either by moving the screen in a quiet body of water or by moving the water column by means of a plunger; the material resting in the latter case on a fixed screen. In both of these cases the upward moving grains will drop back at each return stroke of the plunger and eventually will assume stratified layers, according to their specific gravities, the heavy ones on the bottom and the light ones on top. This is the fundamental principle of the jigging process, which is only limited by the fineness of the grains to be treated.

Bilharz also believes that the particles of material to be treated arrange themselves during their upward travel according to their respective specific gravities and that they remain in the same order during the following downward motion. This opin-

ion is also shared by Professor Robert H. Richards, who treats this subject fully in his book on "Ore Dressing."

Sparre comes to the conclusion that besides the law of *free settling* other forces influence the work of a jig. He believes that, as in jig work, the distances traversed by the grains are quite small, the velocity at the beginning of each stroke has some influence on the work performed and that the different spaces through which the grains pass with an accelerated velocity must be compared in order to arrive at a correct understanding of the jig work.

Sparre computed a table, which shows the starting velocities and the spaces traversed by galena and quartz balls of different diameter, also the resulting differences in the distances traversed during fractions of one second.

The following table is figured in metric measurements. The specific gravity of galena is taken at 7.5 and that of quartz at 2.5 instead of 2.6 in order to get a simpler relation between the diameters. Two sizes of galena are compared with two sizes of quartz having the same settling velocity and one very coarse grain of quartz is considered in order to show that the smallest grain of galena can be separated from the coarsest grain of quartz on a jig, by using only moderate pulsion, not exceeding ⅜ in. lift of the bed.

A comparison of the behavior of grains of the same diameter shows that the difference between the respective distances increases steadily. The quicker falling galena gets farther and farther away from the slower moving quartz. The increase in the distance between the two grains during equal periods of time grows steadily, until after a certain length of time it becomes a constant. But if we study the behavior of a galena grain of 0.5 m/m. and its relation towards a quartz grain of large diameter, we find that the difference in the traversed spaces decreases in proportion to the difference between the diameters of the grains. While the quartz grain of 2.18 m/m. diameter even after 9/10 of a second remains behind the galena grain of 0.5 m/m. diameter, the quartz grains of 9.45 m/m. and 18.9 m/m. diameter advance after 1/10 of a second over the galena grain of 0.5 m/m. diameter.

But even with the above sized grains, the distances between the

Time in seconds	Velocities in millimeters					Total space traversed in millimeters,				
	Galena, diameter in millimeters		Quartz, diameter in millimeters			Galena, diameter in millimeters		Quartz, diameter in millimeters		
	0.5	2.18	2.18	9.45	18.9	0.5	2.18	2.18	9.45	18.9
1/80	101	105	72	73	73	.65	.66	.45	.46	.46
1/40	177	203	134	144	145	2.42	2.49	1.75	1.82	1.82
1/20	245	358	214	270	281	7.88	9.65	6.21	6.88	7.19
1/10	266	506	216	436	499	20.9	32.10	18.40	25.20	27.00
2/10	267	553	267	540	711	47.1	86.00	45.00	75.50	89.60
3/10	267	555	267	554	742	74.10	141.50	71.70	130.40	164.20
4/10	267	556	267	555	782	101.00	197.10	96.00	185.90	242.00
5/10	267	556	267	556	785	127.70	252.60	125.10	241.40	320.20
6/10	267	556	267	556	786	154.40	308.30	151.10	297.00	399.00

TABLE 1

quicker falling galena and the slower falling quartz increases at the start according to the specific gravities of the respective grains. However, this advance of the denser grains is getting smaller in indirect proportion with the difference in the diameters of the grains. The galena grain of 0.5 m/m. diameter has even after 9/10 of a second an advance of 3.3 m/m. over the quartz grain of 2.18 m/m. diameter, but the quartz grains of 9.45 m/m. and 18.9 m/m. diameter are getting ahead after 1/10 of a second, while after 1/20 of a second the advance of the galena grain of 0.5 m/m. diameter over the quartz grain of 9.45 m/m. diameter was still 1 m/m., and over the quartz grain of 18.9 m/m. diameter 0.69 m/m.

If we therefore restrict the total distance through which the grains are permitted to fall to 7.88 m/m., i. e., the distance reached by a galena grain of 0.5 m/m. diameter after 1/20 of a second, and interrupt the motion at that point, the grains will fall through the same space if allowed to settle again. Thus we see that with each repetition of the pulsation the distance between the galena and quartz grains will be increased the same amount, namely, 1 m/m. and 0.69 m/m., respectively, so that, to get a distance of 10 m/m., and 6.9 m/m. ten plunger strokes will be required.

Sparre therefore comes to the conclusion, that by using a correct number and length of plunger strokes, it will be possible to make in a jig a complete separation of materials having different specific gravities.

The theoretical foundation for jig work lies in the fact that the materials to be treated move over small distances only with an accelerated velocity.

In jigging, however, the grains do not only fall in an ascending column of water, but they receive also through the sudden influx of water a certain impulse, which modifies their movements to the same extent as the accelerated settling velocities in a resisting medium, or the law of hindered settling, modifies the jigging process

Sparre, however, believes that the influence of the water impulse can be neglected, on account of the resistance offered to the ascending water column by the screen itself and by the material resting upon it. The irregularities of the interstices

between the particles of the bed are such that a vertical acting water impulse will almost entirely disappear. Sparre considers only the ascending water column as the effective medium and believes that the impulse of the ascending column as well as the suction effect of the descending column are ineffective or at least of little importance.

Rittinger gives a somewhat different explanation of the process of jigging. Guided by a formula developed by him for the starting motion of solid bodies in quiet, ascending and descending water columns, he has calculated the velocities and distances for fractions of a second. In his treatise on ore dressing Rittinger gives a good many tables, showing the behavior of materials of different sizes and different specific gravities. The calculated distances are given for quartz and galena grains of the same diameter, i. e., d = 4 m/m., and for a galena grain of 0.95 m/m. diameter which has the same settling velocity as a quartz grain of 4 m/m. diameter.

It may be seen from this table that the galena grain of the same diameter as the quartz grain advances rapidly over the quartz grain as well as over the smaller galena grains and that the galena grain of equal settling diameter with the quartz grain advances to some extent in the beginning over the larger quartz particle but is overhauled after two seconds by the larger quartz grain.

Table 3 shows that: (1) The smaller of two grains of the same specific gravity rises higher than does the bigger one, and (2) a grain of lower specific gravity of the same size will be raised higher than the one of higher specific gravity, if the ascending column of water is strong enough to lift the grains. (3) A grain of higher specific gravity of two grains having the same settling velocities, rises higher than one of lower specific gravity. If the ascending column of water is not able to lift the grains, they fall in the ascending current and the distances become negative and even then the grain of higher specific gravity advances more rapidly than the grain of lower specific gravity, just as in a quiet body of water.

Table 4 shows the conditions in a descending current of water. With low velocities the galena falls faster than the quartz of the same diameter, as was to be expected from observations made in

DISTANCES AT THE BEGINNING OF THE FALL IN QUIET WATER

Diameter in m/m.	Specific Gravity	Time in seconds										
		0.01	0.02	0.03	0.05	0.10	0.15	0.20	0.25	0.30	0.50	1.00
		Distances in millimeters										
4	2.6	0.3	1.2	2.6	6.9	22.0	42.5	62.9	83.1	103.5	184.2	389.8
4	7.5	0.6	1.9	3.8	10.2	36.5	71.1	110.7	148.9	189.0	355.6	753.2
0.95	7.5	0.4	1.6	3.6	9.1	27.2	47.5	67.8	88.1	108.4	189.6	392.7

TABLE 2

DISTANCES TRAVERSED IN AN ASCENDING COLUMN OF WATER

Diameter in m/m.	Specific Gravity	Time in seconds										
		0.01	0.02	0.03	0.05	0.10	0.15	0.20	0.25	0.30	0.50	1.00
		Distances = s in millimeters Velocity of water column = 0.25 meters, s = minus										
4.	2.6	0.1	0.6	1.3	3.2	9.6	17.1	24.8	32.6	40.2	71.2	148.4
4.	7.5	0.3	1.2	3.2	8.2	28.2	53.4	81.2	109.2	137.8	252.4	539.5
0.95	7.5	0.2	0.7	1.8	3.9	11.1	18.7	26.2	33.8	41.2	71.5	147.3
		Velocity of water column = 1 meter ; s = positive										
4.	2.6	1.3	4.3	8.1	17.6	45.2	74.5	104.1	133.8	163.7	282.7	580.8
4.	7.5	0.2	0.8	1.7	3.7	10.6	18.9	27.3	36.1	44.9	80.1	168.1
0.95	7.5	1.8	5.2	10.0	20.4	49.6	79.3	109.2	139.2	169.2	288.9	588.3

TABLE 3

DISTANCES TRAVERSED IN DESCENDING COLUMNS OF WATER

Diameter in m/m.	Specific Gravity	Time in seconds										
		0.01	0.02	0.03	0.05	0.10	0.15	0.20	0.25	0.30	0.50	1.00
		Distances in millimeters Velocity of water column = 0.25 meters										
4.	2.6	0.4	1.5	3.3	8.5	30.9	60.6	92.7	125.4	158.2	289.5	617.8
4.	7.5	0.6	2.0	4.2	11.1	41.5	84.9	134.6	186.8	240.1	454.6	991.5
0.95	7.5	0.6	2.1	4.3	11.6	39.0	71.0	103.3	106.0	168.5	298.8	624.5
		Velocity of water column = 1 meter										
4.	2.6	1.8	5.9	11.6	26.0	73.7	135.	202.8	222.5	243.6	624.0	2292
4.	7.5	1.0	3.7	7.7	18.9	64.6	130.3	209.9	296.6	386.1	749.9	1662
0.95	7.5	2.3	7.5	14.4	31.5	88.4	156.1	225.9	295.9	366.0	646.3	1347

TABLE 4

a quiet body of water. With higher velocities the quartz advances at first and only after 0.15 seconds does the galena take its place according to its higher specific gravity.

In the same way the smaller of two grains having the same specific gravity falls more rapidly in both currents of descending water at the beginning, but after respectively 0.05 and 0.25 seconds the bigger one overhauls the smaller and quickly passes it.

These observations are important for a clear understanding of the process of jigging.

Table 4 shows furthermore that of two grains having equal settling qualities the one having a higher specific gravity advances more rapidly than the one with a lower specific gravity and that the difference in velocity is greater in a current having a velocity of 1 meter than in a current of only 0.25 meter velocity per second.

From the results of his calculations Rittinger developed the following theory of the jigging process:

"On the down stroke of the plunger the ascending column of water lifts evenly the whole bed as a compact body, without permitting the smaller and lighter particles to rise appreciably higher than the bigger and heavier ones. The heavy, thick body of the material resting upon the screen prevents a free movement of the individual grains. Possibly only the grains of the top layer follow the influence of the ascending water, as they have freedom of action upward.

"On the downstroke of the plunger, the descending current forces all grains to move downwards. The grains occupying the lower strata can move freely and follow the law for short timed fall under moderate velocities of the descending column (Table 4). The grains having a greater specific gravity, either large or small ones, advance over the grains having lower specific gravity, and collect on the screen, whereas the grains with lower specific gravity arrange themselves in higher strata. The grains in the upper strata follow the same law on account of the greater freedom of action and the loose condition of the bed."

Althans admits that the formulæ and observations of falling bodies during a longer time interval and the average velocities derived therefrom for bodies having equal settling qualities can not be used for the study of the jigging process.

In all jigs an intermittent up and down motion in quick succession with only small lifts and drops is used. To accomplish an effective separation the lifting of the material must be carried on under a sharp impulse; the dropping of the bed, however, ought to be as far as possible carried on under free settling conditions. With the rapid oscillations between an upper and lower point of rest, only the different velocities of the grains, acting during a short time and for a small distance, can be taken into consideration.

Althans also states that the influence of the lifting impulse upon the bed can not be definitely and correctly expressed.

Hoppe also takes the stand that the grains of higher specific gravity have a greater tendency to sink in water than the grains of lower specific gravity, so that in any case they advance at least at the beginning of the down stroke of the plunger over the grains of lower specific gravity and are thereby separated from them.

This explains, without considering the influence of the impulse by the current of water, the general action of a jig. Munroe, whose work has been verified by Ladenburg, obtained the following results for settling particles "en masse," i. e., under hindred settling conditions:

$v = c \sqrt{d(s-1)}$ meters per second.

where $c = 0.833$ for small spherical grains, 0.490 for rounded grains, 0.536 for angular grains of uniform size, and 0.307 for large spheres moving in a mass of small spheres when the difference of the diameters is great.

If we take the specific gravity of pure coal at 1.35 and that of the impurities to be removed at 1.50 we get the following ratio of diameters under hindred settling conditions:

Velocity of largest particle of pure coal:

$$v = 0.307 \sqrt{d \cdot (1.35-1)}$$

Velocity of smallest particle of impurity:

$$v_1 = 0.833 \sqrt{d_1 (1.50-1)}$$

$$\text{Therefore } \frac{d}{d_1} = \left(\frac{0.833}{0.307}\right)^2 \times \frac{0.50}{0.35} = 10.5$$

Therefore it would appear that unless the specific gravities of the ingredients of the mixture approach one another quite closely, it is not necessary to size the material in a detailed manner. Indeed Munroe states that for the treatment of fine stuff on jigs, close sizing is a positive disadvantage, as the concentration of the fine material takes place in the small interstitial channels forming the mineral bed.

Bring, however, has shown that the smaller particles of the light material are drawn down between the large particles by the interstitial currents during jigging.

By taking the above ratio of diameters, under hindred settling conditions, we see that if we wash 3 in. screenings, slate as fine as ¼ in. can be removed, and if we wash 1 in. screenings, all impurities larger than 10 mesh will go into the refuse.

The above assumed specific gravities of 1.35 for pure coal and 1.50 for refuse were selected because material with a specific gravity higher than 1.50 contains too much ash to permit it to go in the washed coal. Should such material contain too much fixed carbon to be rejected with the refuse, rewashing must be applied in order to get a clean refuse free from bone coal.

If we review the above expressed theories of jigging, we find that two main opinions exist in regard to the action in a jig.

The one considers that the action in a jig can be explained by the law of equal settling and the other holds that this law is inapplicable, but that only the rules for the acceleration of solid bodies falling in moving water can be considered for a proper explanation of the jigging process. Besides this we find differences of opinion in regard to the forces that act upon the bed and in regard to the manner in which these forces are applied.

It is not very probable that the process of jigging is carried on according to the laws of equal settling. The fact alone, that the product from hydraulic classifiers and "V" boxes (Spitzkasten) can be treated with good results in a jig, is proof that the success of the jigging process rests upon other factors.

It is not easily conceivable that a mixture of grains of different specific gravities and different sizes, which has been produced under equal settling conditions in a horizontally flowing current of water, either with or without the use of an upward-rising column, can be separated under the same physical condi-

tions according to the specific gravities of the individual grains, by using only a different kind of apparatus.

The scientific investigations of Sparre, Rittinger and especially of Professor Richards as well as practical experience, have established without doubt the fact that in the law of equal settling, not only the specific gravities but also the size of the grains must be considered. According to the formula for equal settling: $d_1\ (s_1 - 1) = d_2\ (s_2 - 1)$, the diameters of the grains in a mass of equal settling quality are in reverse proportion to their specific gravities minus one.

Practical experience teaches that in a body of grains produced under equal settling conditions out of a mixture of grains of different specific gravities and different sizes, smaller grains of higher specific gravity are found beside larger grains of lower specific gravity.

Only when grains of different specific gravities, but of the same diameter are subjected to the process of equal settling, can a separation according to specific gravity be accomplished. Then the formula assumes the following form: $d_1 = d_2$ and $s_1 = s_2$. The separate strata contain therefore only grains of the same specific gravity. This condition, however, can never be fulfilled either in classifying over a screen or in a hydraulic classifier.

By pressing the hand flat against the bed of a properly working jig, it can be easily felt that the whole bed is lifted on the down stroke of the plunger. The water pushes through the bed, the separate grains whirl one against the other and assume different positions. On the up stroke of the plunger, the water recedes and the sucking action can be easily felt on the finger tips.

It is doubtful if the different motions, contingent upon each plunger stroke and influenced by the difference in the shape of the grains, can ever be correctly investigated and expressed in a mathematical formula. But it will be permissible to draw conclusions from the behavior of regularly formed grains in either quiet or moving bodies of water, in regard to the possible actions existing in a jig. Guided by the general rules and maxims, derived from the behavior of regularly formed grains in a current of water of known constant direction and velocity, it is possible to form a correct idea of the jigging process.

Sparre has expressed the opinion that the law of free falling bodies can not be applied to the process of jigging, because in this process only small distances through which the bodies fall, can be considered and therefore the starting velocities and the spaces traversed under acceleration must be taken into account. He has made a thorough investigation of the above conditions and has arrived at the following conclusions:

(1) At the end of very small time intervals the velocity of grains having the same specific gravity is the same regardless of their diameter.

(2) Of two grains of equal settling qualities but of different specific gravities, the one having a higher specific gravity advances at the start over the one having a lower specific gravity. Borne extended these investigations to include the behavior of falling bodies in an ascending column of water, having a constant velocity. He demonstrated the following principles:

(3) Of two bodies, having different specific gravities and such diameters as will give them in a given time the same constant velocity, the one with a lower specific gravity has at the start a higher velocity than the one with a higher specific gravity, if the bodies are moving in an ascending column of water of constant velocity.

(4) The time in which the velocity of a grain will become uniform decreases in direct proportion with the diameter and the specific gravity of the grain.

Rittinger also investigated the jigging process. His investigations confirm the correctness of Sparre's conclusions. But in regard to the behavior of solid bodies in an ascending column of water his results are diametrically opposed to those obtained by Borne. While the latter states that a grain of lower specific gravity advances faster than a grain of higher specific gravity, Rittinger is of the opinion that a grain of higher specific gravity has at the start a higher velocity in an ascending column of water.

The behavior of solid bodies in an ascending column of water require therefore still further investigation.

Until this matter has been fully determined, we believe that it will be safe to agree, as Althans and Sparre have done, with Borne in his opinion that the grains of lower specific gravities

advance faster in an ascending column of water than the grains of higher specific gravities.

We are justified doing this, by consideration of the fact that a grain of higher specific gravity offers to the impulse of the water a smaller surface than a grain of lower specific gravity having equal settling velocities and that it will therefore assume the velocity of the ascending column of water much slower than the larger grain of lower specific gravity, which offers to the current of water considerably larger surface to act upon.

Professor Richards has investigated this problem quite thoroughly, using an apparatus which illustrated graphically the behavior of the different grains. In all the diagrams obtained, the curve for the specifically lighter materials rises higher than that for the denser materials. This proves the correctness of Borne's opinion.

In regard to the behavior of solid bodies in a descending current of water Rittinger comes to the following conclusion:

(5) In a swift current the specifically lighter one of two grains having the same diameter, advances at the start, but after a short time interval the denser one overhauls it.

In a slow current the opposite is the case. Of two grains having equal settling qualities the denser one advances over the specifically lighter one.

If we consider the behavior of the materials in a jig in accordance with the above maxims we arrive at the following conclusions:

On the downstroke of the plunger, the water passes through the screen and lifts the bed, whereby the specifically lighter particles will rise higher than the denser ones, inasmuch as the confined space, the direction of the water impulse, the shape of the grains and all the other peculiarities will permit a movement in this direction. At the next moment the plunger starts on its upstroke, the water follows and the grains previously lifted by the water impulse, fall back upon the screen. While, however, formerly the grains with a lower specific gravity advanced, now the opposite takes place. The denser grains drop faster than the specifically lighter ones and therefore the distance between grains of different specific gravities becomes greater with each plunger stroke. We must, however, consider that the time given

for the grains to sink in quiet water is short. The water is only at rest at the change of stroke direction. This period of rest is shorter or longer according to the methods used in operating the plunger. At the termination of the change of stroke and as soon as the plunger obtains its full velocity, the water rushes through the bed and creates a suction effect. This suction is, according to maxim 5, favorable in treating materials of equal settling qualities, but it is detrimental for screened materials.

The scope of jig work is broad. Grains from 10 mesh to 3 in. in diameter can be treated successfully, if the difference in the specific gravities is sufficiently great and the materials adequately reduced in size to make this difference in specific gravity perceptible.

On account of the above, the opinion has gained ground that a close classification of the materials to be jigged is not necessary, but Professor Richards, who has made a thorough study of this problem and who can be accepted as an authority on this subject, says in his book on "Ore Dressing" as follows: "The general practice of the day seems to tend towards a more general application of the English system; that is to say, towards the use of the jig in the treatment of unsized material instead of the hydraulic classifier. While *the treatment of material sized between wide limits is possible and thoroughly practicable,* still the advantages resulting from a preliminary sizing cannot be denied. In the English system itself, when the hutch products of one jig are treated upon another, we are making use of a preliminary sizing. Again, in order to jig an unsized product suction is necessary to effect a separation, and suction, as has been stated previously, results in cutting down the capacity enormously. This point is nowhere better exemplified than in the case of the pulsator jig. The arguments that have been advanced for the adoption of the English system on the ground that equal-settling ratios, many times larger than those obtained under free settling conditions, exist on a jig bed, have been amply disproved. It may be stated that both systems have distinct advantages and that the method adopted will depend largely upon the particular conditions existing in each case."

From the above we can see that a close sizing of the material

to be jigged is not absolutely necessary and that the separation plant can be much simplified and arranged on economical lines without impairing the efficiency of the jigging process.

In coal washeries, Stewart, Baum and Montgomery are washing in their jigs screened coal from 3 in. diameter down with excellent results. If we consider that the difference in the specific gravities of coal and slate is slight as compared with the difference existing in metalliferous ores, we must come to the conclusion, that close sizing, except in a few special cases, is not necessary for the efficient working of jigs and that the slight advantage, which might be gained by it, does not warrant the additional initial expense and increased cost of operation resultant upon the use of the complicated apparatus required for close classification.

The methods used in ore dressing can not, however, be employed in coal washing without some modifications. A coal washery handles a large tonnage of relatively cheap material. Especially the jig, which is the heart of every washery, has to be altered considerably in order to handle the large quantities of a material, the separate particles of which do not show such a marked difference in specific gravity as those of the metalliferous ores. A great number of quite ingenious pieces of apparatus were developed for the purpose of surpassing the simple Hartz jig in both quality and quantity of production.

In the year 1879 there was such an abundance of jigs that a writer of that period exclaimed rather grievously: "During the last 50 years so many partly novel, partly improved devices appeared and disappeared that the metallurgists became absolutely confused."

Since that time the makeup of the jig has not become more complicated, even though the design and details of construction have been considerably perfected. It is not possible, within the scope of this book, to follow all the ideas advanced and which resulted in the construction of some wonderful and curiously shaped pieces of apparatus. It is only possible to give a general outline of the development that has taken place and to observe which ideas have justly disappeared and which deserve our attention.

CHAPTER V

THE EVOLUTION OF THE JIG

The first jig, used in the year 1830 in Saxonia, was a pan or basket jig. A movable sieve full of coal was immersed quickly in a tank filled with water. Fig. 3 shows this, the first jig used for coal washing.

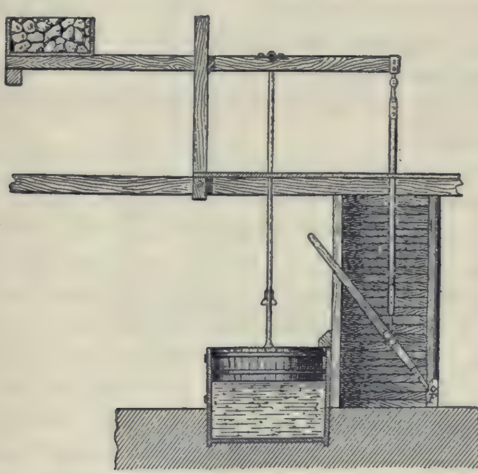


Fig. 3. Hand-operated Jig with Moving Screen

By depressing the lever the sieve is lowered while a counter weight lifts the sieve, as soon as the pressure on the lever is released. This jig differs from our modern machines in the following characteristics: (1) Movable sieve, quiet water; (2) manual operation; (3) intermittent operation. The layers of pure coal and refuse must be scraped off by hand.

To modify these three characteristics in a suitable manner was the first step in the evolution of the jig. In order to clearly understand the manner in which this was accomplished we must

keep in mind the relative importance of these characteristics in regard to the operation of a jig.

(1) *Movable Sieve, Quiet Water.* The sieve is an unyielding body. If it is plunged suddenly into a body of water, the water is forced to pass uniformly through all parts of the sieve; i. e., if the material in the sieve is uniformly distributed. This action of the water loosens up uniformly the material and is therefore favorable for the separation of the impurities. On the other hand, the moving of the sieve full of coal is cumbersome. It requires considerable power and the wear and tear is quite appreciable. Therefore the process of separation is favorable and the mechanical operation unfavorable. The improvement of this operation through the introduction of fixed screens and pulsating water currents was an easy step. Attention had to be paid that the process of separation should not suffer thereby. The change in the moving parts, that is, from sieve to water, was well begun by the year 1840, but jigs with movable screens held their own until the seventies.

This can be accounted for by the existing belief that the so-called "hydraulic jigs" could not separate with the necessary uniformity. Especially in England jigs with moving screens were used to a great extent and in America Stewart brought about an epoch-making revolution with his machine, which held the field for a long time without a competitor.

(2) *Manual Operation.* In moving the sieve by hand, it was possible to loosen up the coal by a quick stroke and to give the different particles plenty time to stratify during a slow up-stroke. This, however, depended entirely upon the skill and the conscientiousness of the operator. It afforded the possibility of good separation without a positive assurance thereof. In introducing mechanical operation, a guarantee of uniformity was assured, but it was necessary to arrange the drive in such a way that it imitated the manual operation. This point, which is no longer of great importance, was for a long time the main issue in the evolution of the jig. Much interest attached to this mechanical problem, and some curious and wonderful devices were developed.

(3) *Intermittent Operation.* The only constant tendency in the evolution of the jig was shown in the effort to replace the

intermittent working of the first machines with an apparatus permitting continuous operation. It did not take long to see the obvious advantages of a continuous process, giving greater production, independence from the operator, saving of labor and a reduction in the cost of operation. On account of the relatively low value of coal, compared with metalliferous ores, the coal washeries were the first to introduce continuous jigging and even if they borrowed the jig from the ore dressing plants, they deserve full credit for having developed successfully the con-

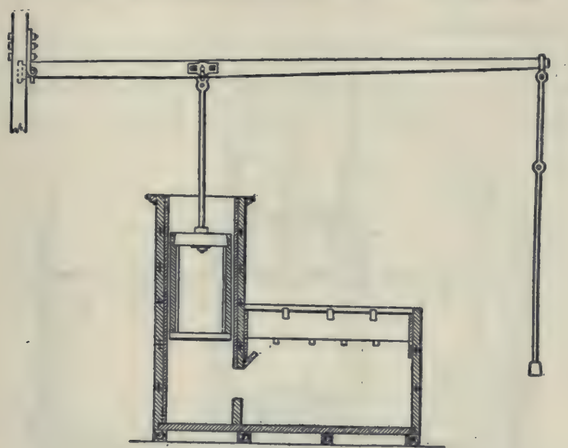


Fig. 4. First Plunger Type Jig

tinuous machine. Berard must be considered the pioneer of this process. He introduced, in the year 1848, his jig in coal washeries and established thereby the basis for the uninterrupted development of the jigging process up to the present time. Ten years after the basket type of jig was introduced, a machine with fixed screen, the so-called "hydraulic jig," made its appearance. Fig. 4 shows this device.

The removal of the washed coal from the screen and the cleaning out of the refuse from the hutch was still performed by hand. It is also surprising to see that the flow of water from the plunger to the screen compartment was throttled or choked down by making an extremely narrow opening in the partition wall. This produced a swift current, which was furthermore

increased by the faulty ratio of the plunger area to the screen area. This swift current of the wash water had the undesirable effect of loosening up the materials in an unequal manner. Those particles nearest to the plunger compartment were more violently agitated than the materials farther away. Instead of reducing or entirely suppressing this undesirably swift current of water by making the opening in the partition wall as large as possible, inventors galore brought forth a good many, nearly useless and often complicated devices to regulate the current and action of the water. Fig. 5 shows such an arrangement in a two compartment jig.

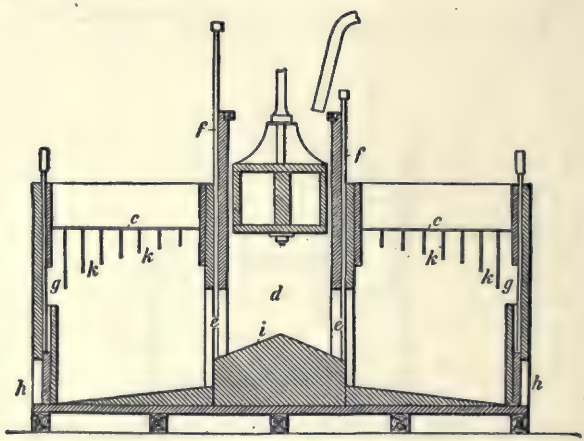


Fig. 5. Arrangement of Baffle Plates under Jig Screen

Only in the sixties was the idea brought forward of transmitting the pulsation of the water from the plunger to the screen in a uniform way, by making the area of both these compartments nearly equal, by avoiding all contractions in the opening between them and by rounding off the bottom of the hutch. Fig. 6 shows some of the proposed forms of the jig tank, from the earliest form at "a" to the present shape at "d and e."

The first step to produce uniform operation was made by the French engineer Lacretelle of St. Etienne, as shown in Fig. 7. He used a grid "b" with bars spaced about 4 in. apart. On top of this is fastened a screen "c" with square openings of 0.5 m/m. (about a 50-mesh screen). This screen is firmly placed

between two others of about 8 mesh for protection. At a distance of about 4 in. above the screen a grating "d" is located, having the bars spaced far enough apart so as to let the material pass freely. The wooden plunger was moved by hand. The

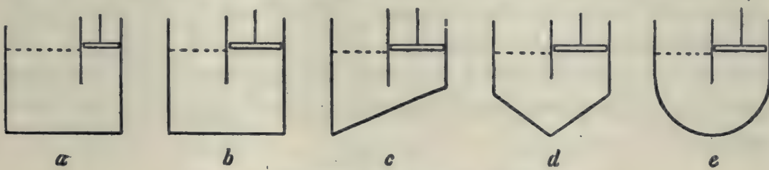


Fig. 6. Different Types of Jig Tanks

position of the grating "d" permitted the continuous removal of the washed product and the operation was only interrupted when the space between the screen "c" and the grating "d"

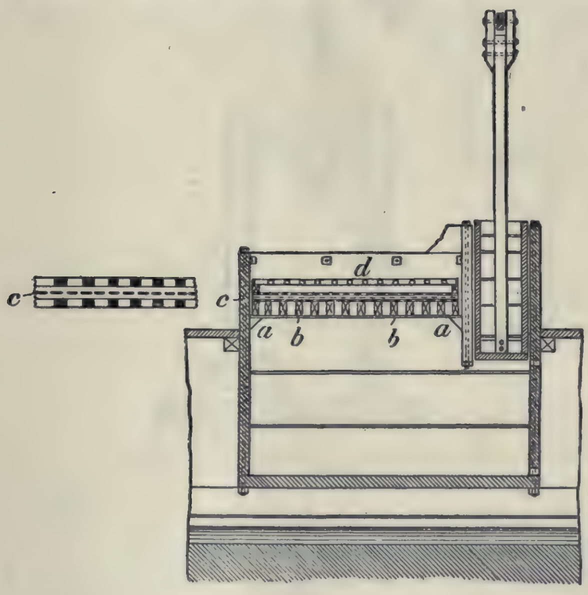


Fig. 7. Lacretelle Jig

became filled with refuse. This was shoveled out by hand, after removing the grating "d."

Even if this apparatus was the first step toward continuous operation, it must be considered as being quite an improvement.

Berard, however, only one year later, i. e., in 1848, introduced a jig with continuous removal of all products. He based the operation of his jig upon two other ingeneous ideas to wit: (1) A crank and link motion produced a rapid down stroke and a slow up stroke of the plunger. (2) Fresh water was introduced underneath the plunger. This tended to neutralize the suction effect of the rising plunger, and permitted the continual overflow of the washed coal and the constant renewal of the wash water.

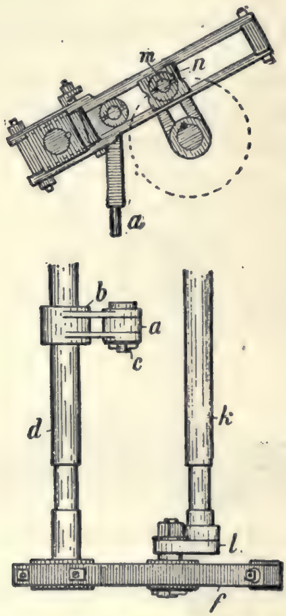


Fig. 8. Berard's Differential Motion

The differential motion used by Berard is shown in Fig. 8, while Fig. 9 gives the construction of his jig.

The screen "a" rests in the jig box at an inclination of 3 deg., sloping from front to back. The jig box is connected with the plunger compartment, in which a plunger "d" moves up and down. On the up stroke of the piston fresh water enters the jig box at "e" which partially prevents the suction effect and reduces the settling velocity of the material upon the screen. On the down stroke of the piston the valve "f" is closed. Dur-

ing this down stroke the material and the excess water are automatically removed. The refuse passes out through the slot "i" and over the dam "h." The opening of the slot "i" can be regulated by a slide "g." The clean coal overflows at the opposite side, passing over a dewatering screen "k."

It is apparent that Berard's jig closely resembles in its fundamentals our most modern jigs.

One would assume that Berard's jig, which was well designed and carefully constructed with cast iron plunger, cylinder and

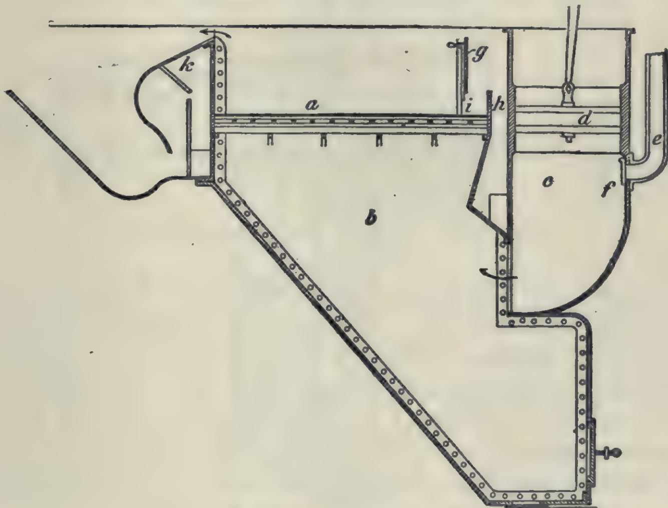


Fig. 9. Berard's Jig

steel plate jig box, would have influenced the whole art of coal washing. This, however, was not the case. Even though his jig was installed at various washeries in France, Belgium, Germany and England, it was severely criticised, mainly on account of the idea, that the wash water should only enter the jig flowing in one direction, so that the separation according to the specific gravities would not be influenced by the return movement of the water.

Meynier in the year 1851 carried through this idea by building a hydraulic jig in which the reciprocating plunger was replaced by a double acting pump, that delivered to the jig box a continuous stream of water, which could be regulated by a gate

valve placed between the pump and the jig. Meynier reports on the operation of his jig as follows: "The working of the jig is so perfect that no particles of slate can be found in the washed coal, neither does the refuse contain any coal."

Nevertheless he changed his jig later on as shown in Fig. 10. He divided the jig in two compartments and following the second compartment he added a series of troughs "c c c" for the purpose of catching some of the middle products.

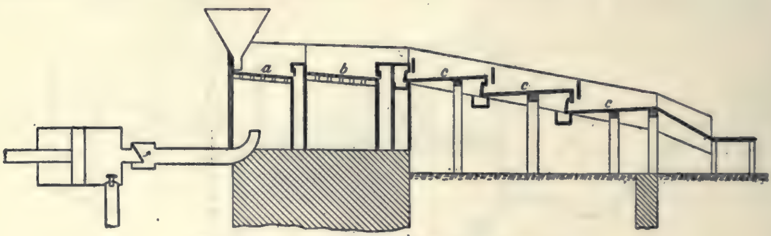


Fig. 10. Meynier's Washing Machine

Meynier's jig must have had, at the time it was introduced, some alluring possibilities. The theoretically perfect separation, according to specific gravities, which was easily accomplished if we accept the inventor's assurance, after only one stroke of the piston, and the fact that it was possible on account of its quiet and steady operation to build for ten times the capacity of other jigs, made a good many friends and users. This jig withstood all competition from other devices for the same purpose up to the eighties.

It was entirely overlooked that the machine, even if several jigs could be operated by one pump, was cumbersome and used much water (25 to 40 gal. per stroke). It is remarkable, therefore, to find the following opinion in *Armangauds Génie Industriel* in the year 1852: "The apparatus does not require any repairs, except the renewal of the screen plates."

Meynier made the mistake of giving preference to minutely perfect work rather than simple and economical operation. With the arrival of more practical experience and a better understanding of the theory of coal washing his jig disappeared from the field.

Meynier was not the only one to use a current of water flowing

in one direction only for the purpose of coal washing. But his successors neglected even the necessary requirement of a continuous operation. DeFrancy and Jarlot thought it to be possible to classify and separate coal ranging from dust to large sized nut, in one and the same apparatus. This machine, shown in Fig. 11, was simple indeed. In the cylinder "a" a perforated piston "b" can travel up and down. On starting the operation,

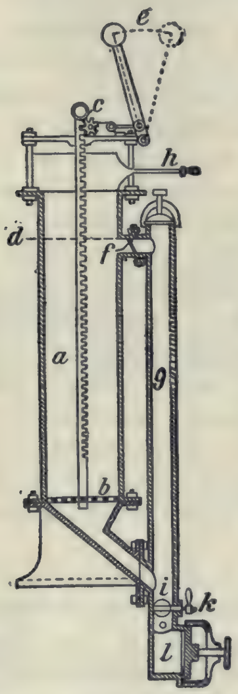


Fig. 11. DeFrancy and Jarlot's Washing Machine

the piston is raised by means of a rack and pinion "c" to the line "d." The cylinder is now filled with water and the space above the piston occupied by nut coal. By disengaging the pinion through the lever "e" the piston is caused to descend slowly, thus forcing the water through its perforations. The coal is thereby held in suspension above the piston. On the end of the stroke, when the piston has reached the bottom of the cylinder, the coal is stratified, with the slate on the bottom, followed in

succession by the coarser coal, the fine coal and the sludge on top. By throwing the pinion into mesh again, the piston ascends. The water above it, which can not pass through the dense sludge, is bypassed through the valve "f" into the down pipe "g" and thus back to the cylinder "a." The piston is now raised to the top of the cylinder and the layers of separated material being scraped off, in succession as they come to the top edge, with the scraper "h." Fine sludge which passes through the piston is collected at "i" and can be discharged into the space "l" through the valve "k." This apparatus—a very interesting toy—has actually been used in many washeries.

Of a more serious character was the washing machine of Lombard, which was introduced in the year 1856 in the Loire district. Developed from a jig, it took only its outer shape, as its operation resembled more that of a hydraulic classifier. Other types of classifiers were designed, but without success. In the meantime the development of jigs was not neglected and besides sensible efforts, a good many foolish ideas were introduced. Berard without doubt had the right basic principle, but in the fifties a good many different ideas prevailed. Baure tried, neglecting continuous operation, to obtain large capacities by using big machines. This resulted in cumbersome apparatus. He used a screen having an area of 21 sq. ft. and could wash over it 70 tons of coal in ten hours, against only seven tons with hand operated jigs.

Gervais' jig, shown in Fig. 12, had a steam operated pan and a steam operated scraper. The jig basket "z" is lowered by means of the steam cylinder "A" and covered with coal. After a certain number of strokes about 4 in. in length, the jig basket is lifted out of the tank "L" and the steam operated scraper "F" pushes the different layers in succession onto a platform "M." This machine is only described here to show that, at a time in which the Berard jig was in successful operation, it was considered feasible to build a jig having a capacity of 2½ tons per hour, employing two steam cylinders.

The jigs of Marsais, Robert, Girard and Flanchon as well as of Ract-Madoux were operated in the same cumbersome manner. They are only mentioned here to show the great variety in jig construction at that time. In the year 1856 a committee ap-

pointed by the *Societe de l'Industrie Minerale* investigated and tested all of the above named jigs. The result of this investigation is especially important, because it proved that it was a mistake to use one and the same type of machine for all sizes of coal. This committee recommended the use of the Gervais, Marsais and Robert jigs for nut coal only and considered the

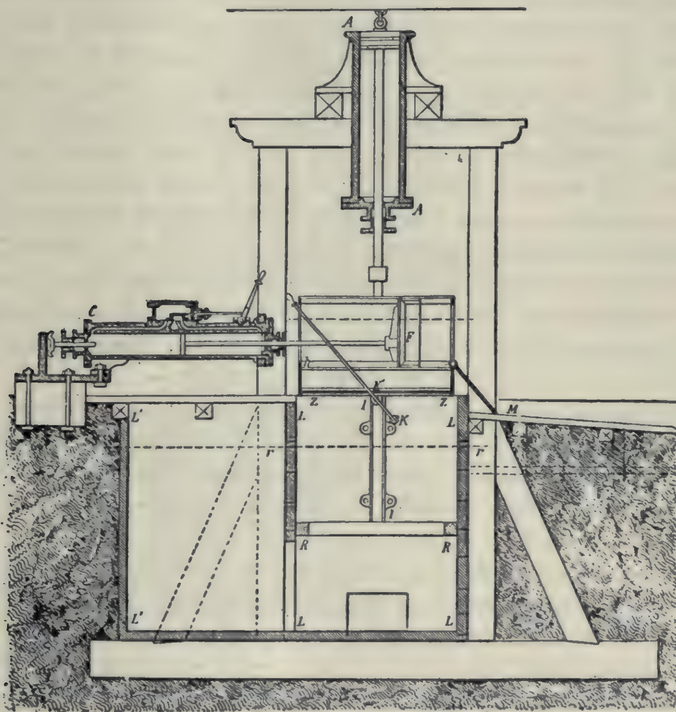


Fig. 12. Gervais's Jig

hand jig, the steam operated jig of Baure and the Berard jig adapted to the smaller sizes.

At that time it was only considered necessary to build the jig intended for fine coal smaller than those for large sizes, to increase the number of strokes and to decrease the height of water pulsation. This latter was arrived at by making the piston area of fine coal jigs much smaller than the screen area. The difficulties caused by the clogging of the fine screen were, however, not

overcome and the washing of fine coal was a troublesome affair until in the beginning of the seventies, Lührig came out with the idea of using an artificial bed on the screen. This type of jig, being at first successfully used in Silesia and Saxony, quickly found its way into a good many washeries and still remains the main type for fine coal treatment.

The Lührig jig was first introduced into America by Alexander Cunninghame, who built an experimental Lührig washery at the City Furnaces of the Sloss Iron and Steel Co. at Birmingham, Ala. Later on, in the year 1894, he built a Lührig washery with a capacity of 60 tons of coal per hour at Carterville, Ill.

The development of the jig from 1850 to 1860 shows that the Berard jig, without fundamental changes found many users, but that otherwise a great variety of ideas in regard to methods of operation, capacity, discharge of material, etc., etc., caused the construction of more or less cumbersome and complicated pieces of equipment and that with the apparatus of DeFrancey, Jarlot and Lombard the fundamental principle of jigging was lost sight of.

In the following decade the development of the normal jig advanced steadily. Sievers, Rexroth, Neuerburg and Revollier improved the methods used in discharging the materials and simplified the drive, without, however, avoiding some mistakes in details.

A description of these machines can be omitted as they may be considered as predecessors of the modern jig. But it will be worth while to study the efforts of the Frenchman Evard, who introduced after ten years of hard work an apparatus which combined all the experience of the preceding ten years and was used to a great extent in France.

The Evard washer consists of a classifier and a circular jig used to separate the middle product coming from the classifier. The classifier starts the operation and avoids the necessity of previous sizing. Fig. 13 shows the classifier.

On the screen piston "a" rests the mass of coal to a height of about 50 in. Steam is let in through a pipe "b" in sharp pulsation, on the outer circular body of water "c-c," in the beginning of the operation with slow and heavy pulsations which become weaker and quicker toward the end of the process. This

brings about the following stratification of the material: (1) Pure slate; (2) a middle product according to size; (3) clean nut coal, and (4) pure sludge.

Only pure slate particles pass through the perforations of the piston. This fine material overflows at "D."

After the jigging has been completed the material is allowed to rest for one to two minutes, after which the screen piston is

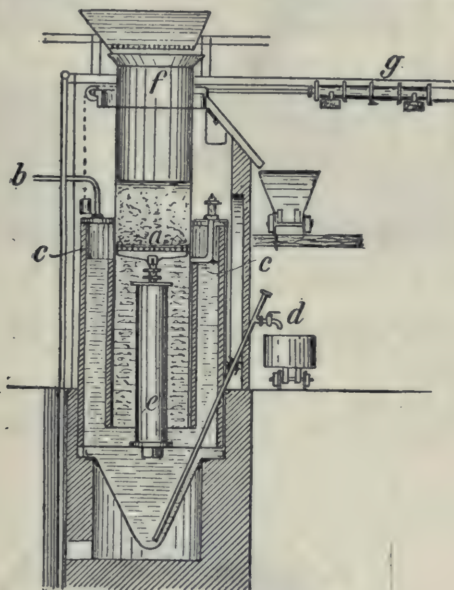


Fig. 13. Evard Classifier

raised by the hydraulic cylinder "e" until each separate strata enters the steel ring "f" which acts as a scraper. By means of the hydraulic cylinder "g" the different strata are pushed off separately. The middle products are carried to the annular jig shown in Figs. 14 and 15.

The annular screen "A" rests in a water tank "B" on rollers and is slowly revolved by an outside gear. This annular screen, however, does not lie in a horizontal plane, but is inclined toward the left at a slope of 1 in 30. The water in the tank is carried at such a level that the lowest point of the screen comes about 8 in. below and the highest point about 4 in. above the water level.

The space inside of the annular screen is occupied by a piston "C" which can be raised quickly by a cam "E" and walking

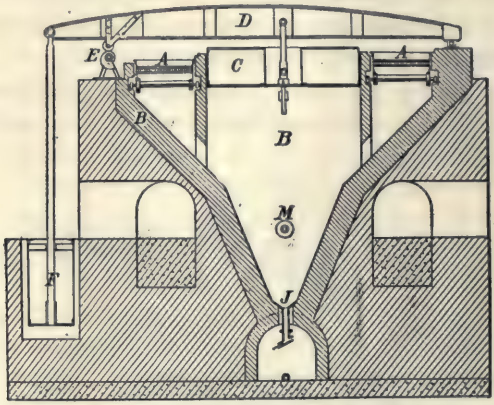


Fig. 14. Annular Jig by Evard. Vertical Section

beam "D." The speed of the descending piston can be regulated by a dashpot "F."

Evard believed that he could pull some of the smaller slate particles through the coal if he reversed the usually adopted

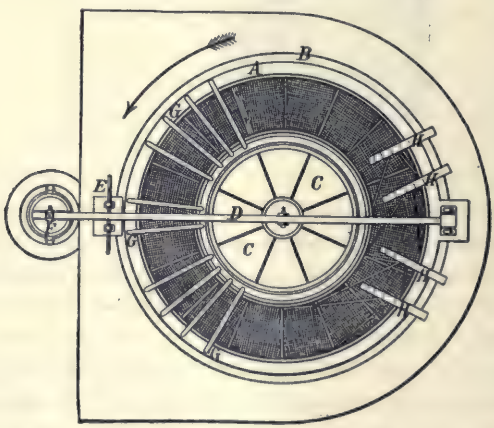


Fig. 15. Plan View of Evard's Annular Jig

method of slow up stroke and quick down stroke. The coal is fed to the jig at a point slightly in advance of where the screen

enters the water (at about "A" in Fig. 15), and is uniformly distributed over the screen by rakes "G." As the screen dips deeper and deeper into the water the coal is subjected to stronger and stronger pulsations which decrease again in the same proportion after the screen has passed the deepest point of immersion. In travelling forward the coal rises above the water and is partly dewatered by the suction caused by the pulsation. Further on the stratified materials are scraped off separately by means of scrapers "H-H" set at different heights. The middle products are further treated on another annular jig. This jig was built with a diameter of 32 ft. 6 in. and had a capacity of 60 tons per hour.

The Evard machine had at first sight a good many alluring qualities. Much attention was paid to separating the materials according to the specific gravities and the whole process of washing was performed in only two or three machines. The cost of operation was low as few men were required and the capacity was, at that time, considerable. Each separate piece of apparatus, however, had a good many complicated mechanical details. The failure of a single one of which caused the shut-down of the whole washery. These difficulties outweighed the superiority of the small number of machines and the urgent call for simplicity sounded the death knell for Evard's jig, which combined in an ingenious manner the ideas of different inventors.

In a manner similar to the Evard machine all other types of apparatus, resembling jigs, disappeared to make place for the normal coarse and fine coal jig, which arrived in the course of a steady evolution. This has finally attained its present position as the only successful apparatus for washing coal.

The development of the jig was carried on with the full knowledge that it was possible theoretically to excel the work of the jig. Practical experience, however, has taught us not to exchange the simplicity and assurance of uninterrupted operation of a normal jig for any theoretically more perfect but practically defective apparatus having an excessively minute method of operation.

CHAPTER VI

OTHER METHODS OF WASHING

Before the further treatment of the products from the jigs can be described, it will be necessary to illustrate a number of methods of separation, developed independently from these machines. Some of these methods are still in use at the present time and others have been abandoned. Among them are the following:

(1) Trough washers, (2) air separators, (3) centrifugal separators, (4) separators using dense liquids, and (5) separators taking advantage of the different shape of the coal and slate particles.

All of the above methods will be treated in this chapter only when and in so far as they were used as an independent process in the treatment of the total mass of screened coal. The use of some of these devices for other purposes, such as dust collectors, dewaterers and sludge separators will be described in other chapters of this book. The washing of coal in trough washers is equally as old as the washing in jigs. It was used extensively in France and Belgium the year 1840 onward.

The construction of a trough washer is ilustrated in Fig. 16.

Fig. 16. Trough Washer

The raw coal is fed to the trough by a launder "a" and thoroughly stirred by hand in the first compartment "b." In this compartment the heavy slate and the largest pieces of coal settle to the bottom. The lighter material overflows in the compartment "c," where a mixture of coal and lighter refuse settles to the bottom. The pure coal is collected in the compartment "d" and the sludge overflows with the wash-water in the launder "e." The compartment "b" is emptied from time to time and

its contents, containing about 80 per cent. of good coal are rewashed in jigs.

The main characteristic of the trough washer is the great amount of water required. This often reaches a quantity three times as large as the amount of coal washed. The trough washer did not produce clean refuse and required jigs for rewashing the material. It was only a matter of convenience that kept these washers going for such a long time. The lack of all mechanical devices and moving parts was certainly an alluring characteristic and a great many inventors tried to improve the trough washer in such a way that they could compete with jigs. From 1850 to the end of the last century the trough washer of

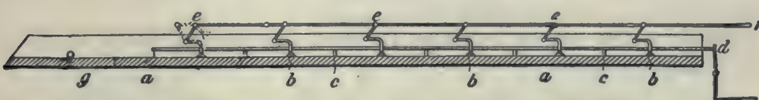


Fig. 17. Bell Trough Washer

"Bell" was extensively in use in England. Fig. 17 shows this apparatus.

The water and the coal flows through an inclined trough "a" which contains riffles "b." These riffles catch the refuse. The rakes "c" are moved to and fro by means of a rod "d." The clean coal and the water overflows directly into a railroad car. When sufficient refuse has been accumulated, the flow of water is interrupted and the riffles are raised by means of the bell cranks "e" and pull rod "f." The refuse is now washed down with a separate stream of water and leaves the trough through the opened gate "g." The Bell trough washer was used for fine screenings only, as at that time the nut coal was only sized and not washed in England.

Elliot introduced as late as 1895 a trough washer that could be operated continuously. This is shown in Fig. 18.

This washer consists of a steel trough 60 ft. long having a slope of 1 in 15. A centrifugal pump "b" delivers the water to the trough. The quantity of water can be regulated by a valve "c." Any excess flows back into the pump tank. The coal is delivered to the trough by a launder "d." The current of water is regulated in such a way that the clean coal flows over

to the dewatering screen "e," while the refuse settles to the bottom of the trough. An endless scraper conveyor removes the refuse. The height of the flights and the speed of the conveyor are dependent upon the amount of refuse and the size of the

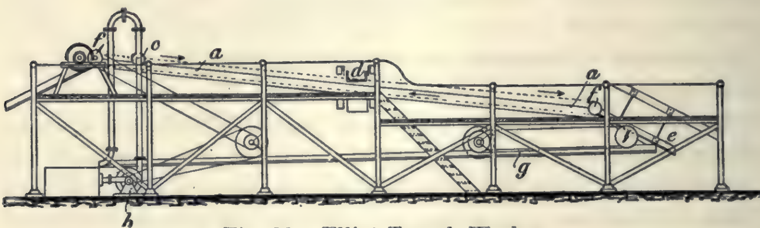


Fig. 18. Elliot Trough Washer

material. The water passing through the screen flows back to the pump tank.

In the year 1882 Bangert built a simple washing machine on the principle of a hydraulic classifier, as shown in Fig. 19.

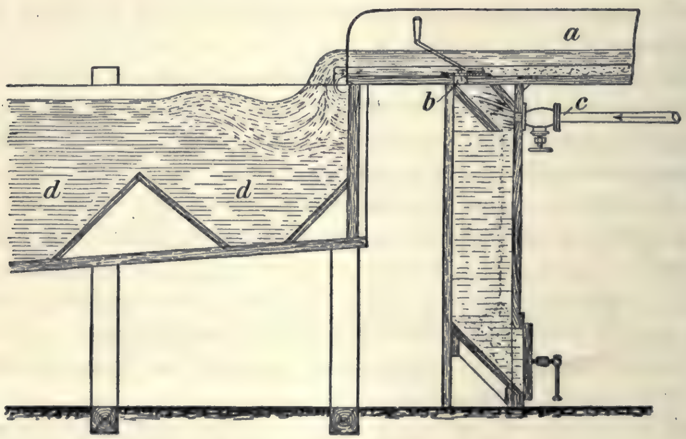


Fig. 19. Bangert Washing Machine

The crushed coal is carried in a stream of water through the box "a." The refuse, which settles to the bottom, is discharged through a movable slot "b," where it meets a current of water "c" which carries back into the box "a" any good coal which may have passed out with the refuse. After passing through

the "V" boxes (spitzkasten) "d" the coal is rewashed in jigs. Bangert therefore used his apparatus only as a preparatory unit to facilitate the work of the jigs. On account of the simple construction and the efficiency of the apparatus it is used even at the present time for a preparatory treatment of excessively dirty coal.

Rhum in 1885 introduced in Bohemia a belt washer illustrated in Fig. 20.

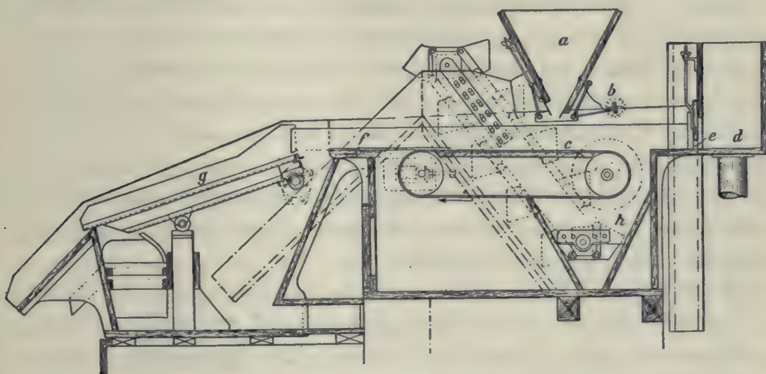


Fig. 20. Rhum Belt Washing Machine

This washer operated quite successfully with coarse coal. The coal is fed on an endless belt "c" by a shaking feeder "b" underneath the hopper "a." The wash water flows over the belt "c" out of a box "d" and can be regulated by a gate "e." The water current carries the clean coal to the dewatering screen "g" and the refuse, following the belt, falls in the tank "h," out of which it is removed by a perforated bucket elevator. It is readily conceivable that every change in the character of the coal, in the velocity of the water current and the speed of the belt will influence the result of this machine. It is not possible to compensate these different qualities as readily as this may be done in a jig, where the frequent and repeated pulsation of the water take care of any irregularities in the character of the coal.

The trough washers and hydraulic separators have been treated in some detail, because efforts to use them as an independent washing apparatus have continued up to the present time. It is

an open question if those efforts should be seriously considered. There is no doubt that the operation of a trough washer, if freed from moving parts, is simpler than that of a jig. It is also possible to reduce the immense water consumption, by circulating the liquid with a centrifugal pump, as Elliot did, up to the point when the wash water becomes too thick. This occurs mostly with fine and friable coal. Practical experience has taught us that all trough washers introduced up to the present time suffer from two fundamental disadvantages: (1) In order to produce clean coal it is necessary to waste a good deal of coal with the refuse. This disadvantage can be remedied by rewashing the rejected material, but this destroys the simplicity of the operation. (2) The effect of a flowing stream of water upon the material to be separated is so delicate, while the least change in the velocity of the water current and the character of the raw coal influences the result of washing to such an extent that it is extremely difficult to obtain uniform results.

Were it possible to build a less sensitive apparatus of this type, it would deserve our fullest attention and recognition, even at the present time. Thus far, however, this problem has not been successfully solved.

At present trough washers are restricted to use as a preparatory apparatus and for the treatment of sludge.

Air Separators. The separation of coal and slate by means of air currents can be treated briefly.

Air is too sensitive a medium to be used in a commercial way for an exact separation of mixed materials containing particles of different sizes. The absolute weight of the different particles influences the separation in an air current to such a degree that the material must be sized closely to obtain even a half decent separation. With unsized material, the air does not produce clean products, but only those having equal falling velocities.

These can only be separated into products possessing equal characteristics by a subsequent classification. Furthermore, the first requisite for separation by air is absolute dryness, which is not one of the characteristics of coal as it comes from the mine.

In the year 1858 Schmitt invented an ingenious apparatus for separating ore and coal by means of air currents. He did not introduce the air in a continuous flow but intermittently.

Gaetzschmann was of the opinion that if an air current was used the intermittent puffs of air could have no advantage and that the mechanical devices necessary to produce them would complicate the whole apparatus. It also would be difficult to obtain the necessary uniformity in the separate puffs of air.

Schmitt's apparatus was ingeniously designed, but was never introduced into actual practice.

An extensive air separation plant was built in the year 1871 at the mine "*Rhein Preussen.*" Primarily it was intended to treat the coarse coal with air, but this proved to be impossible and only fine screenings were subjected to air separation. After a good many changes in the apparatus there remained only a device which blew off the dust from the coal. For this purpose the apparatus proved to be quite efficient and was used until the year 1890 at different mines in Westphalia. The results obtained with an air separator showed that this method, as an independent process of separation, was not successful and on account of the character of the medium used for the separation it holds out no promise of success in the future.

This has been conclusively proven by a test made at the *Serlo* mine near Saárbrücken. This test was carried on to find out, if it would be possible, to separate, prior to washing, the fine particles of slate and fireclay from the coal by means of compressed air for the purpose of getting a clearer wash water.

The apparatus used for this test was arranged in such a way that compressed air with a pressure of from 5 to 10 lbs. was blown through a slot 24 in. long into a stream of fine coal (of a size that had passed a six mesh screen) coming from a hopper. The separate coal and slate particles were blown away to different distances and therefore distributed over a large area. The deposited material was divided into zones each 10 in. in width. Samples were taken from each zone and separately analyzed. The results from this test showed that the air current did classify the material somewhat, but that nowhere was there a distinct separation of coal from slate. This trial therefore gave a negative result.

Separation by Centrifugal Force. The idea of using centrifugal force as an independent means for separating coal from slate prevailed to a great extent during the period from 1853

to 1863. Froehiich in the year 1853 built a barrel apparatus. In 1858 Zemlinsky designed a centrifugal washer in which he used also an ascending current of water. Mackworth, from 1860 on, used his centrifugal washer quite extensively in England and Belgium. At the same time Imbert constructed an apparatus having a rotary motion, and in the year 1862 Cadiat introduced his centrifugal washer.

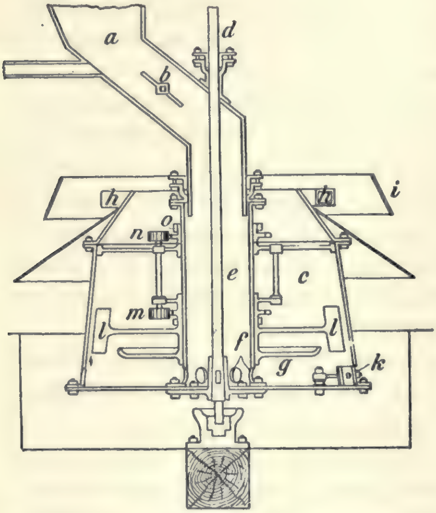


Fig. 21. Cadiat Centrifugal Washer, Vertical Section

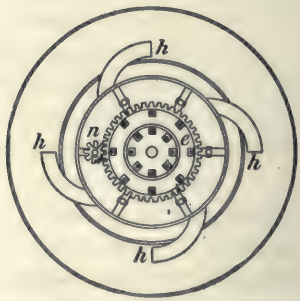


Fig. 22. Cadiat Centrifugal Washer. Plan View

It will be necessary only to describe this latter machine, which as the result of ten years of development, demonstrates with sufficient clearness that centrifugal force for the purpose of commercial coal washing is totally inefficient. This force requires an apparatus which is vastly more complicated than a jig.

Figs. 21 and 22 show the Cadiat washer in section and ground plan.

The feed pipe "a" with butterfly "b" enters the washing tank "c" through a stuffing box. The tank revolves around the shaft "d." From the inner space "e" the coal passes through the openings "f" in the outer annular space and is carried to the circumference by the disks "g." The lighter par-

ticles ascend close to the outer wall and overflow through the openings "h." The refuse settles at the bottom against the gates "k," which at the full speed of the apparatus are kept closed by the centrifugal force. At intervals the machine is slowed down. Springs attached to the gates then overcome the centrifugal force and open the gates, through which the refuse is discharged. The arms "l," fastened to a sleeve, agitate the material. The arms are revolved by means of gears and pinions. The gear meshing with the pinion "n" is held to the pipe "e" by a friction ring "o" which permits a certain slippage if the resistance of the coal becomes too great.

It will not be difficult to choose between a jig and this complicated machine, especially if we consider the rough treatment to which the coal is subjected in this device.

Centrifugal separation soon disappeared. At present, however, centrifugal force is used for drying washed coal, in the same manner as it has been employed for the same purpose in other industries, especially sugar refining.

A device, combining the actions of a hydraulic classifier and a centrifugal machine is the Robinson washer, which since the year 1890 has been used extensively in England and is still in operation at a good many plants. This washer was introduced into America by the Jeffrey Manufacturing Co. The first installation was made in Alabama, where it opened the field for coal washing. Credit is due to the untiring efforts and the mechanical genius of Erskine Ramsay for the rapid introduction of this washer. In the year 1912 there were still eight Robinson-Ramsay washers, with a total capacity of 3,200 tons of coal per day in operation in Alabama, and six Robinson-Ramsay washers with a total capacity of 4,360 per day in use in Illinois, besides a number of scattered installations in Georgia, Tennessee and Ohio. Fig. 23 shows the Robinson-Ramsay machine as installed in Alabama.

In the washing cone "a," which is 11 ft. high and has a diameter of 11 ft. 6 in. at the top and 22 in. at the bottom, the stirring arms "b" are suspended. These arms are revolved by a bevel gear "c" at a speed of from 20 to 24 r.p.m. A pulsometer "d" takes the water from "e" and forces it through the pipe "f" in the washing tank. The unsized raw coal is fed to the washer through a chute "g." The separation is carried on by

the influence of the stirring arms and the ascending current of water under hindred settling conditions. The water current carries the clean coal to the top of the cone, where it overflows on the screen "h." This screen is 4 ft. 6 in. wide by 15 ft. long and placed at an inclination of 30 deg. It is made of manganese bronze and has ⅜ in. round perforations. The refuse sinks to the bottom of the cone and is discharged by means of two steam-operated slide gates. The flight conveyor "i" carries the clean coal to the loading chute "k." The fine coal, which

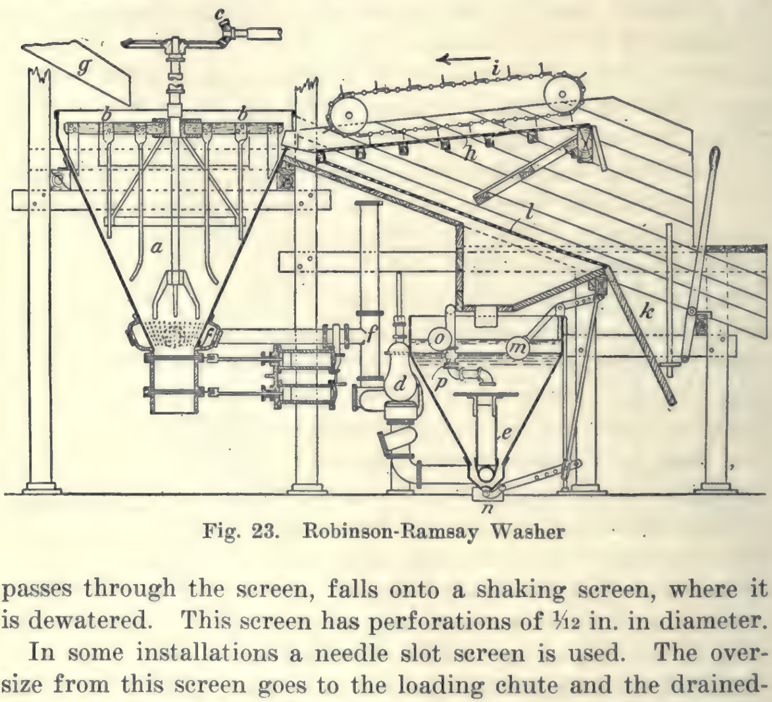


Fig. 23. Robinson-Ramsay Washer

passes through the screen, falls onto a shaking screen, where it is dewatered. This screen has perforations of 1/12 in. in diameter.

In some installations a needle slot screen is used. The oversize from this screen goes to the loading chute and the drained-off water flows in the Ramsay sludge tank, which is shown in detail in Fig. 24. In the English and the earlier American plants this tank was merely a sump for the pulsometer. But the fine material carried over with the water caused rapid destruction of the pipes, valves and pulsometer. It also accumulated in the tank and had to be shoveled out every day.

Mr. Erskine Ramsay, at that time chief engineer of the Tennessee Coal, Iron & Railroad Co., devised a tank that overcame all

these troubles. The Ramsay sludge tank made the Robinson washer an efficient and successful machine. As shown in Fig. 24, this is a steel tank, cylindrical in section at the top, funnel shaped at the bottom. In this tank is a circular deflecting plate "a." The water, charged with fine coal and impurities, is delivered into the top at the center. Thus there is an even distribution over the entire surface of the plate. The flow of the water, on

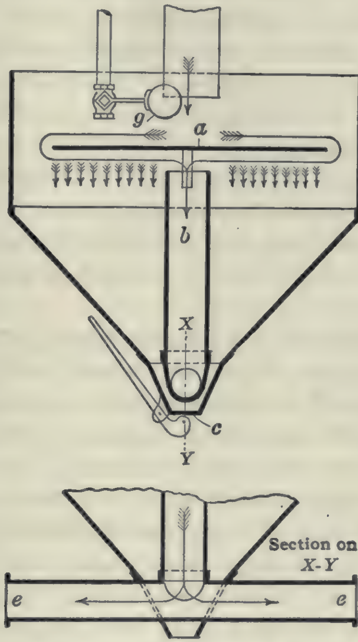


Fig. 24. Ramsay Sludge Tank

entering the tank, is indicated by the arrows. The fine coal particles are carried along by this current of water while the impurities, owing to their greater specific gravity, settle out of the current, as indicated in the illustration, into the comparatively still water below the level of the mouth of the pump-supply pipe "b," and collect in the bottom of the tank. From here the refuse is removed by means of a valve "c" discharging the sludge into a trough, by which it is carried to the refuse car.

The relation between the diameters of the deflecting plate and

the tank is a detail depending on the amounts of coal and of impurities in the fines and on the difference in the specific gravity of the materials. With too small a plate the impurities will go to the pump with the coal. With too large a diameter the coal will not be carried along with the current but will be lost with the slate. Once regulated for a given coal, the results are very satisfactory.

Fitted to this tank is a valve for supplying the fresh water needed by the washer, automatically regulated by a float "g." The water, freed from its heavy impurities and augmented by the necessary make up, is taken by the pulsometer through the central pipe "b" and the connections "e, e," and pumped directly into the washing cone. This is an innovation on the former practice, the old plan being to pump into a tank 40 to 60 ft. above the bottom of the washer, with a discharge pipe from this tank to the machine, in order to maintain a constant head. In the newer installation the same object is accomplished at less expense.

The pipes between the pulsometer and the washer are connected to a standpipe, 80 ft. in height and open at the top. This acts as a balance on the inflowing current and is of special advantage when, as sometimes happens after a stoppage, the material in the washer becomes packed. The pulsometer then forces the water up the standpipe, until a head is developed sufficient to force a way through the obstructing material. The washer is driven by a single steam engine with cylinder 10 x 16 in. One man does all the work at this machine. He must watch the engine and keep it as well as the other machinery properly oiled; operate the main slate valves three or four times an hour, and also the sludge-tank valve and load the washed coal into the railroad cars. He is by no means overworked in attending to these duties, and will have ample time to operate the refuse car. For the same capacity, even a trough washer can hardly excel, if it can equal, this labor record.

The capacity of a Robinson-Ramsay washer is 60 tons of raw coal per hour. The average water required for one ton of coal is 35 gal., and the general efficiency of the machine varies from 55 to 65 per cent.

The advantages of the Robinson-Ramsay washer are:—Low

cost of installation, low cost of operation, compactness, ability to treat with fair results unsized coal. The disadvantages are:—Low efficiency, small capacity, high consumption of water and an unavoidable loss of fine coal.

Separation with Dense Liquids. Berard used in the early days of coal washing solutions of chloride of zinc and calcium chloride with a specific gravity of 1.4 to determine the degree of purity of the washed coal. For the separation of coal in a commercial way Sir Henry Bessemer proposed in the year 1858 the use of dense liquids. He advocated solutions of ferro-chloride, barium-chloride, potassium-chloride, etc., etc., which were waste products from chemical works. Englinger in 1859 proposed the use of a common salt solution for the same purpose.

The idea itself is of an alluring simplicity. All sizing can be avoided and no mechanical equipment is required. It is only necessary to scrape off the clean coal floating on the surface by means of rakes and to dispose of the refuse by means of a screw conveyor or elevator. It would also be possible to produce three products by dividing the operation into two stages. In the first stage, by using a very heavy solution, the heavy refuse would be separated, and in the second stage, by using a lighter solution, clean coal and a middle product could be obtained.

Theoretically the above is correct, but practically there appeared difficulties which forced an abandonment of the process. In the first place this process is too sensitive. The specific gravity of clean coal is never uniform but varies between 1.2 and 1.4. The refuse shows still greater variations, i. e., from 1.5 to 3.5. A jig does good work, even if the character of the raw coal changes during the operation, as long as a difference in the specific gravities of the material exists. The process of Sir Henry Bessemer permitted, however, only a separation of a material having a constant and uniform character, as it was based upon a solution with a fixed specific gravity. Furthermore, the difficulty arose of keeping the solution always at the same density. It was also necessary to free the washed coal from the adhering solution by a subsequent washing or rinsing with fresh water. The dense liquids, furthermore, are rather expensive, thus increasing the cost of the operation.

For coal to be used for coke making this process is entirely

unsuitable, as the chloride salts adhering to the washed coal have a most injurious effect upon the brick work of the coke ovens. The process has been tried on a large scale in Germany. At the *Laura* and *Bolhorst* mine near Minden a large and expensive plant was built for the purpose of using this process. After an exhaustive test under actual working condition, extending over a long period, it was abandoned, as the process proved to be a total failure.

Separation According to the Shape of the Particles. The idea of separating coal from slate according to the different shapes of the respective particles is based upon the observation that frequently the coal breaks in the shape of cubes, whereas the slate occurs in flat slivers. This observation, however, does not hold good in a general way. The slate is not the only material to be removed. Most of the other impurities, such as pyrite, fire clay, and bone coal, do not break in flat pieces, and even slate breaks sometimes in big lumps. Under certain conditions coal will break in flat pieces. Any method of separation based upon the difference in the shape of the particles can not be used under all conditions, but only as an expedient at mines where the different shape of the coal and slate particles is reasonably constant and distinct.

This method found its greatest field of usefulness in the anthracite region of Pennsylvania, where mechanical slate pickers can be found in many breakers. Separation according to a difference in shape of the material has, however, a promising future. The idea can not be rejected, but its use must be closely restricted, to avoid failures, such as have occurred during the last 20 years.

Separation according to the shape of the pieces is only possible under certain favorable conditions, i. e., when the coal and the impurities show a constant and sufficiently great difference in the form of their respective particles. In this case the method has great advantages as it does not require water as a separating medium. In all other cases it can be used to good advantage for special purposes, such as a preparatory cleaning prior to washing. The Bradford breaker operates upon a somewhat similar idea.

Conclusion. The results obtained with the above described methods and apparatus can be summarized as follows:

Trough washers are only adapted for the very fine coal or for the removal of fireclay and mud.

Ascending current washers deserve the credit of having opened the eyes of the coal operators to the benefit derived from improving the coal by washing, but on account of low efficiency they have been supplanted by jigging, which, owing to its simplicity and satisfactory efficiency, is far ahead of all other methods.

Air separators are important for the purpose of removing and collecting the dust.

Centrifugal separators can not compete with the other methods, but centrifugal force is used to some extent for the drying of coal.

Dense liquid separators have proved failures.

Separation according to the shape of particles is to be considered only in special cases. It can be used as a preparatory process.

The products resulting from the foregoing operations, if wet processes only are considered, are washed coal from 3 in. in diameter down, dirty wash water containing fire clay and sludge and refuse. It has always been clear that the first two of these products need further treatment before they can be used to the fullest advantage. The washed coal must be dewatered, the wash water must be clarified, and the sludge removed. This clarification must be carried on to such an extent that the water can be either returned into the system to be used over again or that it can be let run away without polluting streams and natural water courses.

CHAPTER VII

DEWATERING AND DRYING OF WASHED COAL

Washed nut coal forms a loose mass, which permits an easy and quick draining off of the water. In the early days of coal washing the coarse material was dewatered on screens placed at the overflow from the jigs. Later on, with an increased capacity of the washeries, draining screens in front of each jig were no longer sufficient. The large quantity of coal to be handled had to be stored in loading bins at a distance from the jigs. Devices for dewatering remained in principle the same. Screens with perforations smaller than the respective sizes of coal were universally employed for dewatering of the washed coal. From the simple fixed screen progress led to revolving and shaking screens. If the coal was sized after washing, one portion of the sizing screens, which are mostly located on top of the loading bins, is used for the dewatering of the nut coal in such a way that the water is drained off together with the fine screenings.

Dewatering of Fine Coal. The dewatering, or rather drying, of the fine coal is a much more difficult problem. Fine coal if wet forms a dense, compact mass which contains too much water for use in either coke ovens or boiler furnaces. The wet coal has also the further disadvantage of freezing solid in the winter time. The excess water increases the weight of the coal and most consumers object to paying coal prices for moisture. The drying of the fine coal has for a long time been a sore point, and even now it presents great difficulties. For this reason it was proposed to screen out all coal below ⅛ in. and mix the raw fines with the washed fuel.

This method offers the simplest solution of the difficult drying problem, but can only be used if the ash and sulphur content of the washed coal are thereby not materially increased. This, however, is hardly to be expected, as no material improvement can be accomplished by washing fines below 10 mesh. If, how-

ever, the addition of the raw fines should increase the ash and sulphur in the washed coal above a desired amount, it would be better to load the fines in the raw state, or to use them for fuel purposes.

In the early days the washed fine screenings were collected in settling tanks, which were shoveled out by hand when full. The water overflowed the tanks, carrying with it most of the sludge. This method of dewatering was inefficient. In addition to the high labor cost it was necessary to subsequently air dry the coal. With the increased capacity of the washeries there was not sufficient time available to do this and it became necessary to find

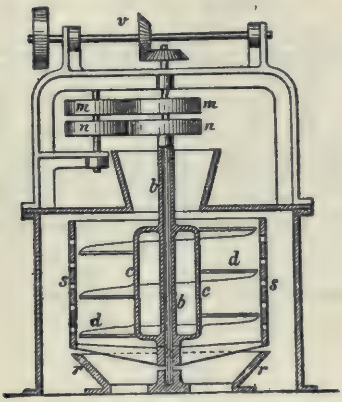


Fig. 25. Hanrez Centrifugal Coal Dryer

better methods. Centrifugal force was used in other industries for dewatering and it was quite natural to try it for the same purpose in coal washeries. Hanrez, in 1867, invented a centrifugal coal dryer shown in Fig. 25.

The vertical cylinder "s" having a perforated mantle, is revolved by means of the shaft "a" and countershaft "v." This shaft is surrounded by a sleeve "b" which is turned by means of the gears "m and n" in the same direction but at a somewhat higher speed. On this sleeve a flat helix "d" is fastened, which reaches close to the cylindrical screen "s." The screen makes 300 r.p.m. and the helix 304 r.p.m. The coal delivered to the machine at the top is forced against the mantle of the cylinder "s" and at the same time, on account of the difference in speed,

carried downwards, where it falls in the hopper "r." The water passing through the screen runs off at the outside.

No evidence can be found in contemporary publications that the Hanrez dryer was used to any great extent. In the second part of this book the development of centrifugal dryers will be further treated.

In the seventies the fine coal was sluiced with the wash water from the jigs into settling tanks and recovered by elevators having perforated buckets. The washwater carrying with it the sludge, overflowed the tanks. This method had the decided advantage that it did not require any separate apparatus. It was only necessary to adapt the existing elevators to this purpose. Dewatering elevators were greatly improved and will be described more in detail later on. At times, however, the inventors, never idle, were carried away with the idea as demonstrated in the dryer of Riehn, Meinicke and Wolf, used in the year 1877, in the Pilsen district. This dryer is shown in Fig. 26.

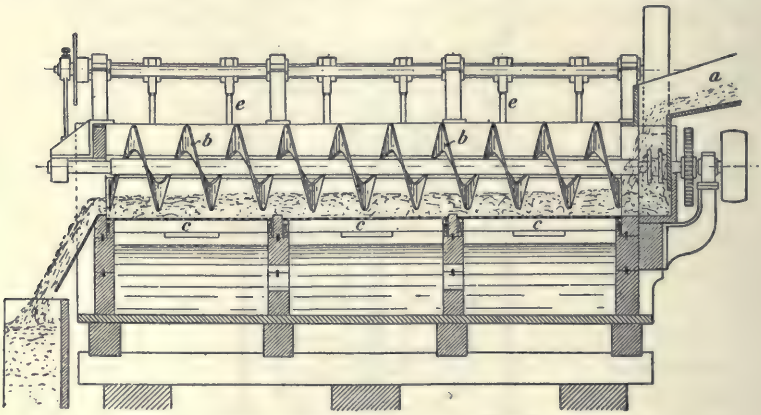


Fig. 26. Riehn, Meinicke and Wolf Washed Coal Dryer

The fine coal and the wash water are sluiced through a trough "a" into a three-compartment tank. A screw conveyor "b" carries the coal forward along a trough the bottom of which is perforated. The water in the tank does not quite reach up to the screen but overflows at a lower level. Behind each screen compartment is a plunger compartment, similar to that found

in a jig. The plungers have a quick down and slow up stroke. On the down stroke the air is forced through the screen, thereby cleaning the perforations and loosening up the material carried upon it. On the up stroke of the plungers air is sucked through the coal, carrying with it the water adhering to the particles. The collected sludge is discharged at the bottom of the tanks.

This apparatus did excellent work, but on account of the excessive cost of operation, was never used extensively. During this period no further improvements were made and dewatering was in most cases accomplished by simply letting the water drain off in a natural way. All efforts were concentrated to make the elevators and conveyors as far as possible suitable and efficient for the purpose of dewatering the coal. In the second part of this book the modern methods of coal drying will be described.

CHAPTER VIII

WATER CLARIFICATION

The methods used for the clarification of the wash water and for sludge recovery at washeries have the combined purpose of using the sludge otherwise carried away with the outflowing wash water and of obtaining sufficiently clear water to be used over again. The wash water must be cleared to such an extent that a continuous circulation can be carried on, as the use of fresh water, on account of the great quantities required, would increase the cost of washing to a considerable extent. Theoretically the process of clarification should be carried on in such a way that only sufficient fresh water will be required to make up for the loss of water carried away with the washed coal and the refuse, and also that lost by evaporation and leakage.

The methods of water clarification depend entirely upon the nature of the raw coal. Friable coal which shatters in crushing and which contains a great amount of fireclay will require more extensive and carefully designed clarification plants than a raw coal which does not break up quite so fine and which is freer of fireclay.

The oldest and simplest means of clarifying water consisted of large settling ponds in which the sludge was permitted to settle. After one pond was filled up with sludge a new one was installed or the walls of the first one were built up higher. These settling ponds, however, required immense ground space while later on two clearing basins were installed which were used intermittently. If the first basin became filled, the water was run into the second and the sludge removed from the first. This method of water treatment is shown in Fig. 27.

The dirty water flows at first through the pipe "a" into the tank "b." The sludge settles to the bottom and the clear water overflows at "c." When the tank "b" has been filled with sludge the pipe "a" is turned into the tank "d" and tank "b"

can be cleaned through the opening "e." Similar installations can still be found at or near the older washeries. The main disadvantage was that the sludge had to be shoveled out by hand, which is a costly operation.

The use of mechanical means for removing the sludge was the next step in the development of water clarification. In the year 1880 "*Spitzkasten*" were used. These permitted a continuous operation. The sludge was withdrawn from the apex of the *Spitzkasten* and carried in a sluiceway to a settling tank out of which the sludge was conveyed by means of a dewatering elevator

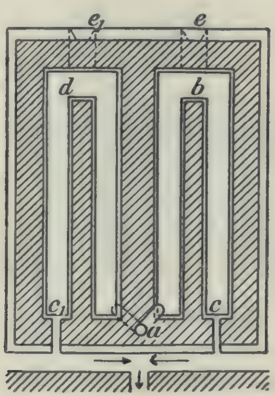


Fig. 27. Settling Basins for Water Clarification

to the fine-coal bins. The outflow of the sludge from the *Spitzkasten* was regulated by a valve or cock and was hardly ever continuous.

In some installations the *Spitzkasten* were consolidated into one large settling cone similar to the Callow tanks used in ore dressing. One of the first and best arrangements of this kind is the Ramsay sludge recovery tank used in connection with the Robinson washers. To make the process of sludge recovery still more automatic and continuous, narrow and long settling tanks were installed in which slow-moving scraper conveyors or even screw conveyors collected the sludge which had settled out on the bottom of the tank. On the end opposite to the inlet of the dirty water the bottom of the tank was depressed to form a sludge

pit or sump out of which an elevator carried the sludge to the fine-coal bins.

A similar device, using an endless belt instead of a scraper conveyor has been invented by Bache at Kladno and is shown in Figs. 28 and 29.

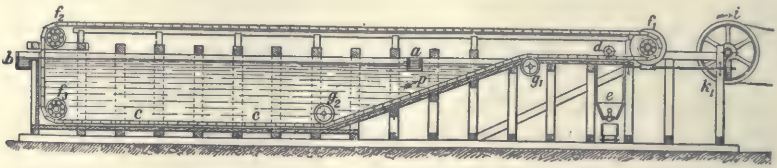


Fig. 28. Bache Settling Tank for the Recovery of Sludge. Vertical Section

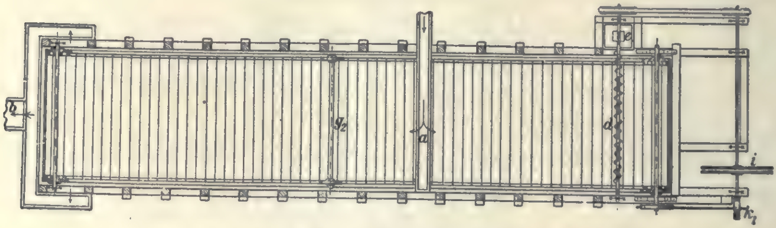


Fig. 29. Plan View of Bache Settling Tank

The endless belt "c" traveling over and guided by the rollers "f_1-f_2-f_3-g_2 and g_1" in the direction of the arrow "p" is carried close to the bottom of the settling tank. The dirty water enters the tank at "a" and the cleared water overflows at "b." The sludge settles to the bottom on the belt and is carried in this way out of the tank. A revolving helix "d" scrapes the sludge off from the belt and drops it in the hopper "e." This and similar arrangements were partly successful, but they did not clear the water sufficiently, so that subsequent clearing apparatus was made necessary.

An absolutely quiet body of water is required to settle the fine material. It is a fundamental contradiction to employ large tanks in order to neutralize the velocity of the water current and to destroy at the same time the still water body by moving parts passing through it. Efforts were made to disturb the water as little as possible by reducing the speed of the belts or conveyors. The Bache belt had a speed of only 6 in. per minute, but this

did not give sufficient capacity, this being only 1,600 lbs. of sludge per hour. In America flight conveyors are largely used to collect the sludge which has settled in the settling tanks.

None of the installations described in the foregoing brought about a sufficiently perfect clarification of the wash water. The moving conveyors disturbed the body of the water too much to permit perfect settling; the water overflowed too rapidly to drop all of the fine particles and the resulting sludge was too liquid to be used advantageously without further dewatering. The question of an efficient way of handling and preparing the sludge is still far from being solved in a satisfactory manner.

The most modern type of sludge recovery and water clarification apparatus—one that promises to become an important part of any coal washery—has been borrowed from the ore-dressing plants where it has been used satisfactorily for many years.

This apparatus is the Dorr thickener, which will be fully described in the second part of this book.

In a general way the utilization of untreated sludge is still a sore point and even at the present time immense quantities of fine coal are simply wasted. This problem has been sadly neglected and no other part of a coal washery can show such primitive and wasteful arrangements as that devoted to water clarification and sludge recovery notwithstanding the optimistic statement of G. W. Evans, coal mining engineer of the Northwest Experiment Station, Bureau of Mines, at Seattle, who said at the International Mining Convention held at Vancouver in March, 1919, that "A coal cleaning plant operating along most modern lines does not waste very much except the color in the water. Probably some enterprising engineer will attempt to recover the color by means of an Oliver filter."

The universally customary method of simply wasting the sludge and the difficulties and expense of an efficient method to recover this material have brought about the fact that sludge recovery has not been developed to the same degree as the separation of the coarser coal. The latter has arrived at a settled final period, whereas sludge recovery requires considerable improvements before it can be considered as satisfactorily solved. With the majority of coal washeries the sludge recovery is only a question of economics.

CHAPTER IX

TREATMENT OF SLUDGE

In considering the development of sludge treatment we can not overlook the fact that in the early days no sharp and fine distinction was drawn between fine coal and sludge. At the present time we consider as sludge only such material as is carried away with the water overflowing the settling tanks. In the early days, however, the term sludge had a broader meaning as all coal which passed through a 6-mesh screen was called sludge.

Fine coal and sludge were not separated one from the other after leaving the jigs and the dewatering of the fine material and the sludge recovery were carried on in one and the same settling tank. This classification was only changed after it was discovered that it was not possible to clean in a jig the fine particles held in suspension in a current of water, but that a material from ⅛ to ⅜ in. in size could be successfully treated in a jig. This knowledge brought about a method by which the dirty sludge-carrying water was clarified separately from the fine coal, by regulating the water current in such a way that only sludge was carried away with the overflowing water. It also developed the idea that if sludge should be treated successfully it must be through the employment of different and new methods.

Dor was the first to build an apparatus for the specific purpose of treating sludge. He installed his apparatus at the Esperance mine near Seraing, Belgium.

Fig. 30 shows this apparatus, which can be designated as a hydraulic classifier. The results obtained with this apparatus are of interest because of the further development of the process of treating sludge.

The sludge resting on the screen "a" is agitated by a water spray coming through a sprinkler head "b." The sludge passing through the screen drops into a cylinder "c," which terminates in a conical bottom. A fresh water current, which can be

regulated by a valve "d," ascends in this cylinder and carries the clean coal to the top where it overflows. The impurities sink and are discharged at "e."

It was possible at the Esperance mine to reduce the ash from 42.5 per cent. to from 12 to 15 per cent. At another mine it was noticed that the overflowing coal, which was sluiced over two "*Spitzkasten*" contained in the first *Spitzkasten* 12 to 14 per cent. of ash and 20 per cent. of ash in the second *Spitz-*

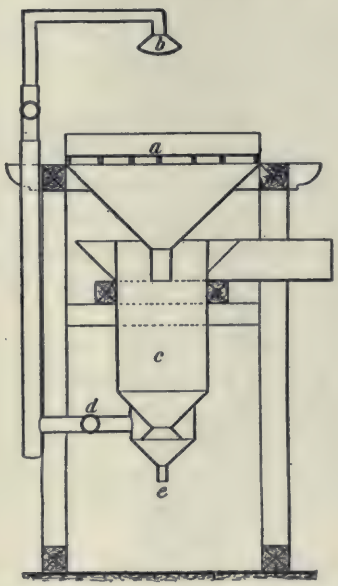


Fig. 30. Dor Apparatus for the Treatment of Sludge

kasten. Therefore the sludge higher in ash settled in the second *Spitzkasten.*

The relatively favorable results obtained at Esperance can be explained by the fact that the term sludge was broadly applied and that here this material was relatively free from fireclay.

The results obtained in the *Spitzkasten* showed that in the treatment of fine sludge the conditions were reversed. Contrary to the action in the separation of coarser coal, in this process the coal settles first while the impurities are carried farther forward. The reason for this phenomenon can be easily found. When, in

the preceding separation, all fine coal which was not carried away as fine sludge had settled out, it can be readily seen that the same must also hold good, but in a higher degree, in regard to all impurities of equal or smaller size. In the sludge we have therefore only the finest, almost microscopic, particles of impurities, which since they are mostly fireclay, are held in suspension in the water. Coal, however, has even in the finest sizes a distinct sharp granular structure, which can not be held in suspension in water. This consideration gave the idea that the treatment of sludge must consist in a removal of the fireclay and not in the separation of the other impurities.

Artois, in the year 1879, designed for this purpose an extremely ingenious but complicated apparatus for the treatment of sludge and fine coal. The Artois cradle washer was further more complicated by the idea of limiting the use of fine coal jigs to material coarser than 6 mesh (4 m/m.). The inventor therefore was compelled to arrange his apparatus for the combined washing of fine coal smaller than 6 mesh and also sludge. The apparatus is shown in Fig. 31.

On a longitudinal shaft "a-b" a trough is suspended in a water tank. This trough has two compartments "A" and "B" and receives a double motion. By the lever "c" it receives an oscillating crossways movement, while the cam "d" imparts to it a sharp lengthways stroke in the direction from "d" to "e" intermittent with a slow backward motion under the action of the spring "e."

The material, after some of the dirty water has been drawn off in a concentrating tank is delivered onto the first screen "a." This screen has a fine mesh. The sludge is carried by the repeated pulsation of the apparatus onto the plate "f" while the dirty water passes through the screen and is discharged from the apparatus. This process can be assisted by the fresh water sprinkler "g."

Passing under the spreader "z" the material enters the second compartment "B" having a curved bottom plate "h." At "r" is a screen with fine mesh, which permits the continuous passage of fresh water from the water tank. This fresh water carries the clean coal over the steep front wall "p" into a com-

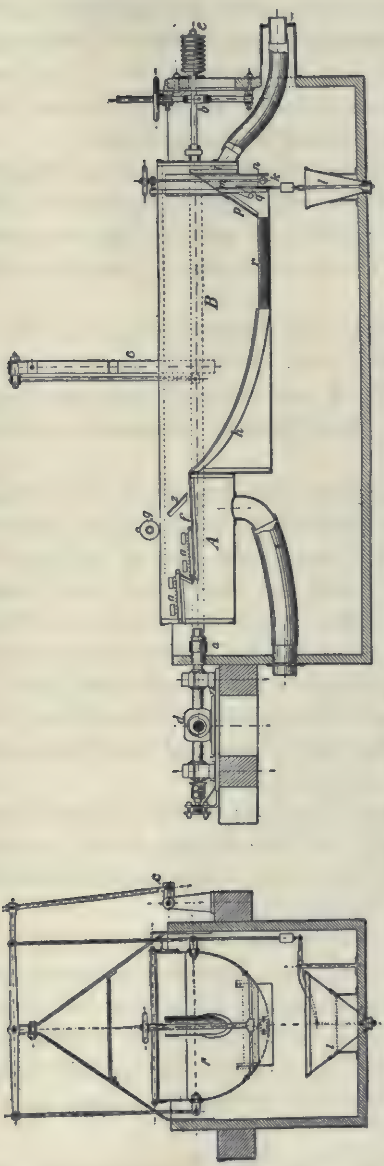


Fig. 31. Artois Apparatus for the Treatment of Sludge

partment "i" where it is discharged from the apparatus. The impurities settle to the bottom and pass through the perforated portion of the plate "p" and the slot "q," the opening of which can be regulated, into the hopper "l." The first compartment "A" serves only as a sludge washery, whereas the compartment "B" is used for washing of the fine coal.

Artois' machine found extensive use in Belgium, France and the Sarre district, but was finally abandoned. For the washing of fine coal the simple and efficient jig was sufficient and for the treatment of sludge alone such a complicated apparatus was not required.

It must be noted, with some surprise, that the idea developed in the compartment "A" of Artois' apparatus was not immediately followed up. It was not until 1901 that the idea was taken up again. In the meantime the treatment of sludge was totally neglected.

Harman, in the year 1898, had the idea of using the difference in the size of the particles of coal and the impurities for a dry classification, which was in this case at the same time a separation. For this purpose the sludge had to be dried and this was accomplished by means of a screw conveyor. The shaft and the flights of this conveyor were hollow and heated with exhaust steam. From the dryer the sludge dropped onto a screen having about 80 meshes per lineal inch. This divided the material into two products, a fine floury material with high ash and a coarser grained material with less ash.

Nothing has been heard about this apparatus in actual practice. The necessity for this drying of the sludge and the difficulty of screening off the very finest material made the apparatus useless for actual operation.

Karlik in 1901 took up the idea of Artois in his belt machine. Kohl followed him the next year with a screening apparatus and in 1905 Zorner added another device for the treatment of sludge. All the above named machines use the principle of washing off the fireclay with the dirty water and as they belong to present-day equipment, they will be described more fully in the second part of this book.

It must be noticed that these devices reduced at times the ash

in the sludge from 40 to 8 per cent. But the loss of coal carried away with the dirty water was considerable and the treatment of sludge is a problem which has not yet been solved in a satisfactory manner.

CHAPTER X

CONCLUSION

The sludge disposal is the final process in coal washing. In regard to the general arrangement of a coal washery it must be stated as important that it has always been considered advantageous to eliminate as far as possible all mechanical means for conveying the materials from one unit to the next. The different units should be arranged in such a way that by gravity only, or by the use of the wash water, the materials can be moved through the whole washing plant.

Where washeries are located on level ground this is only partly possible and elevators and conveyors must be installed. In the early washeries the mistake was made of spreading them out in a horizontal direction and installing between each unit a separate elevating device. This necessitated a great number of individual drives, requiring constant repairs, a great number of spare parts and consumed excessive power. For this reason the modern washeries are built with the units arranged vertically, thereby concentrating all elevating machinery at the incoming end of the plant. This simplifies the machinery, condensing it into a few heavy but carefully designed elevators, driven by large motors that can be operated with a higher efficiency than a great number of smaller ones.

The modern Anthracite Coal Breakers are built on this principle and the raw coal is elevated from the mine tipple to the top of the breaker by means of a gun-boat running on an inclined track. Only lip-screen material and waste rock are reelevated. The Alliance breaker of the Alliance Coal Mining Company at Kaska, Pa., described in "Coal Age," Number 14, Volume 18, September 30, 1920, is the most modern exemplification of the above principle.

PART II

CHAPTER XI

PROCEEDINGS AT THE MINE

The production of a clean product makes the operation of a mine more economical than is the case where ''everything goes'' and is also more favorable for the operation of a coal washery. The mine operation becomes more economical on account of the smaller amount of useless waste material hoisted. A coal washery can then operate under more favorable conditions because of the following reasons: (1) The capacity of each individual piece of apparatus becomes greater when less impurities have to be removed. (2) The percentage of washed coal or the yield from a given amount of raw material is increased. (3) Wear and tear of the apparatus is reduced since coal does not cause as much wear as the heavier and harder impurities.

Conditions in a mine, which would permit the hoisting of absolutely clean coal are seldom found. Such conditions would reduce the process of preparation to a simple classification into the different sizes. Even in an absolutely clean coal bed, this condition will not be completely fulfilled. The possibilities presented by the natural conditions will be limited by the goodwill of the miner and his willingness to load only clean coal.

Consequently the aim of a mine superintendent can only be to prevent as far as possible the loading of dirty coal. The technical means of doing this are numerous and can only be here indicated, since they belong to the art of mining coal. Some of them are: (1) Taking advantage of the slate bands, partings and middlemen in undercutting and snubbing. (2) Mining only the clean portion of the bed and letting the mixed parts remain in the roof or on the bottom. (3) Careful timbering and lagging if necessary, to prevent the draw slate from the roof being mixed with the coal. (4) Careful gobbing to keep the floors clean. The above will help some, but it will never be possible to

prevent absolutely the mixing in of some impurities with the coal at the face.

The loading of slate with the coal is highly convenient for the miner and often of pecuniary advantage to him. The picking out of the slate, before shoveling the coal into the pit car takes time and it is more convenient for the miner to load everything that has been shot down. A direct advantage of loading slate with the coal exists if the miners are paid by the weight of coal they send out. The heavy slate secures a full weight even if the cars are not topped.

The only method now in use to control this loading of slate is the collection of a fine for loading dirty coal. Such a docking system furnishes a point of dispute between the miner and the operator and a just and effective docking rule is not a simple matter. The possibility of loading clean coal is never the same at different mines and even in the same mine it may vary at the different faces. In most districts a docking schedule has been prepared in which the fine is represented by a deduction of a certain amount of coal while in some cases a premium is given for clean coal loaded. The docking schedule in force in Alabama is given below: [1]

Typical Docking Schedule in Effect at Pratt Seam Coal Mines—Alabama

1 can slate	No dockage
1½ cans slate	1 ton dockage
2 cans slate	1½ tons dockage
2½ cans slate	2 tons dockage
3 cans slate	3 tons dockage
4 cans slate	4 tons dockage
5 cans slate	See Superintendent.

A can of slate averages 45 lb.
A mine car averages 1600 lb.

Typical Docking Schedule, in Effect at Nickle Plate Seam Mines, Alabama

1 can slate—give miner 1 ton coal	
2 cans slate	No dockage
2½ cans slate	1 ton dockage
3 cans slate	2 tons dockage
4 cans slate	3 tons dockage
5 cans slate	See Superintendent.

A can of slate averages 45 lb.
A mine car averages 1600 lb.

[1] Supplied by courtesy of Erskine Ramsay, vice president Pratt Consolidated Coal Co., Birmingham, Ala.

TYPICAL DOCKING SCHEDULE, IN EFFECT AT BIG SEAM MINES, ALABAMA

½ can slate—give miner	1 ton
1 can slate—give miner	½ ton
2 cans slate—give miner	¼ ton
3 cans slate	No dockage
4 cans slate	½ ton dockage
5 cans slate	¾ ton dockage
6 cans slate	1 ton dockage
7 cans slate	1½ tons dockage
8 cans slate	See Superintendent.

A can of slate averages 45 lb.
A mine car averages 3500 lb.

TABLE 5

A simple example will show the importance of strictly enforcing the docking rules.

A mine hoists daily 2,000 tons of dirty coal. The limit of slate permitted in each car of 3,500 lbs. is 140 lbs. or 4 per cent. This means (since without doubt all miners will take advantage of this minimum) an involuntary excess hoisting of 80 tons per day. When now, on account of a change in the conditions or through "kicks" of the pit committee the minimum is raised to 350 lbs. of slate per pit car or to 10 per cent., the excess hoisting assumes the figure of 120 tons daily. An increase of 6 per cent. in the slate allowance carries with it the necessity of hoisting 120 tons of rock.

The importance of the above in its effect upon a coal washery will be apparent from the two following assumptions: (a) A washery will handle per hour 180 tons of raw coal (200 tons of mine-run will be handled per day without being washed). With a slate allowance of 4 per cent. we will get $\frac{1{,}800 \times 96}{100} =$ 1,728 tons of washed coal. (It is assumed for the sake of simplicity that the washed coal will be perfectly clean.) With a slate allowance of 10 per cent. we will get $\frac{1{,}800 \times 90}{100} = 1{,}620$ tons. Thus we see that an increase in the slate allowance from 4 to 10 per cent. will reduce the output of washed coal by 108 tons per day.

(b) A washery will produce per day 1,800 tons of washed coal.

In this case the input must be increased by the amount of slate allowance. With 4 per cent. of slate allowance the extra input will be: $\frac{1,800 \times 4}{100} = 72$ tons. With a slate allowance of 10 per cent. this extra input will amount to $\frac{1,800 \times 10}{100} = 180$ tons. Thus with an increase of 6 per cent. in the slate allowance the input is increased by 108 tons, or if the washer can only handle 180 tons per hour the working time of the washery will be increased $\frac{60 \times 108}{180} = 36$ min.

The above examples are merely schematic. They show that in case (a) an immediate loss of revenue would result while in case (b) the cost of operation would be increased and the capacity of the washery would soon be insufficient to take care of the excess of raw coal.

Of no less importance than a just docking rule is its constant control.

At mines where picking belts are used, it is comparatively easy to pick out the slate from each pit car load, if the picking tables, which in this case become docking tables, are located between the dump and the screens, so as to catch the whole pit car load. At a mine in Illinois, the coal passing over the docking belt can either go to the crushers, or if containing too much slate, can be diverted by a by-pass into a railroad car, where the slate is picked out, collected and tagged with the check number of the respective miner for his inspection. The speed of the docking belt and the intervals between dumps is so regulated that a distinct demarcation line between two successive pit car loads is maintained.

At mines where no docking or picking belts are installed, a few cars are picked during each day's run, at random. These are carefully unloaded, a shovelful at a time, and the entire contents of each car closely inspected.[1]

[1] "The Ramsay Mine-Run Sampler," by H. S. Geismer, *Coal Age*, Vol. 11, No. 14.

The weak point in this method is that only a few cars can be so inspected during a day's operation, and many miners who are willing to take chances load cars that should be condemned, without being detected. Another point to remember is that during the morning the miners generally load cleaner coal than they do late in the evening, when they are cleaning up the rooms. Thus it is hard to judge a man's average work by a single car.

Erskine Ramsay, first vice president and chief engineer of the

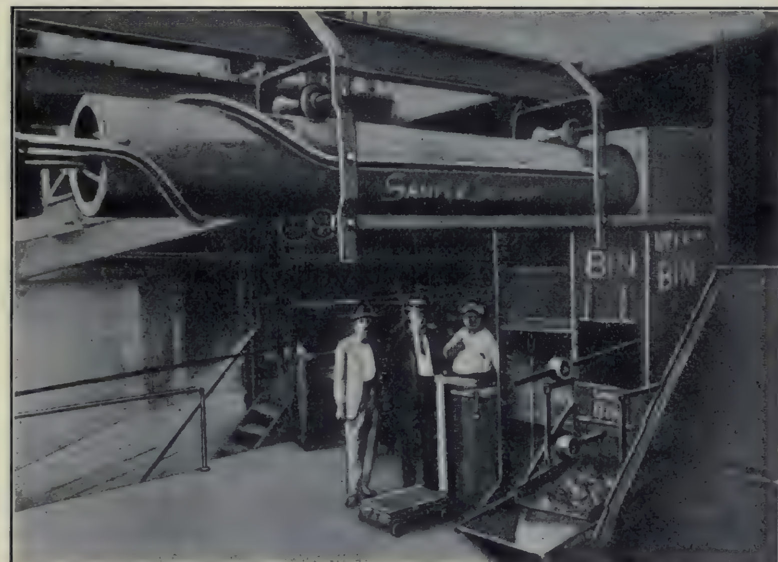


Fig. 32. Ramsay Mechanical Sampler

Pratt Consolidated Coal Co., an Alabama corporation, has been experimenting for several years to perfect a mechanical sampler that would make possible the testing and inspection of a large number of mine cars without the necessity of actually unloading their contents. The experiments were carried on at the tipple of the company's mine at Banner, Alabama.

The contrivance finally perfected, the one that has been installed as part of the regular equipment at the mine, is fully illustrated in Fig. 32. On July 18, 1916, letters patent No. 1,191,227 were granted to Mr. Ramsay covering the invention.

The sampler consists of a scoop made from a piece of 16-in. wrought pipe about 13 ft. long from which a piece about 3 ft. long in the top half at one end has been cut. This scoop will hold approximately a 100-lb. sample. It is placed underneath the regular dump.

This scoop is pushed out by means of an air cylinder so that it comes directly underneath the stream of coal as it is being dumped from the car. By means of the twisted guides, the scoop is revolved as it returns from its position under the chute and empties its sample of coal into a small bin. From this bin the material is dropped into a second bin, and from here it is fed onto a small shaking screen.

The screen separates the coal into two sizes. While the lump and nut coal is slowly traveling across the shaking screen, an attendant picks out the rock and other foreign matter. This screening of the sample expedites the work of the picker and makes it more effective. No attempt has been made at Banner to determine the amount of rock in the fine coal, but if it should appear that some of the miners were shooting up their slate so as to be able to load it out without being detected, the screenings from the sample could easily be tested by the float-and-sink method. After finishing with each sample, the attendant weighs the rock, slack and lump coal and records the percentage of each.

The object in having two bins, one above the other, is to provide a storage for one sample while a second is being fed out slowly onto the shaking screen.

One man operates the entire mechanism, obtaining as many as 100 samples in a shift besides picking out the slate, weighing the lump, slack and slate and making the necessary record. This record when carefully kept enables the operator to keep a close tab on his miners and also allows the miner to compare notes with his fellows, which makes it possible for the conscientious miner to get credit for his work.

When the scheme was first proposed, some were of the opinion that the 100-lb. sample might not be representative of the entire amount of coal in the tram-car; but the results obtained from the device, when checked with rejections from the washer, seem to indicate that the sampling is fairly representative. It is well

to recall that a 100-lb. sample from a mine car is a relatively large amount, compared, for example, to the average sample taken from a railroad car under the methods at present in vogue.

The accompanying charts in Table 6 show graphically how the percentage of rock in the coal was reduced by the installation of the sampler. The device was installed on March 20, but the men were not notified until the twenty-sixth day of March.

Chart A gives three curves, all of them estimated as percentages of the entire output of the mine covering the period from March 19 to June 1.

Curve No. 3 shows the total amount of refuse taken from the coal after it is loaded by the miner expressed as a percentage of the entire output; it was obtained by adding the weight of the refuse separated at the washer (curve No. 2) and the weight of the refuse thrown out by hand from the picking tables (curve No. 1).

All the coal as it comes from the mine is screened; the lump and nut is passed over picking belts, and the slack is taken to a coal washery.

The curve on Chart B is based only on the mine cars that were actually sampled during the same period.

Charts C and D give the results as affecting two individual check miners, selected at random from the tonnage sheets.

Not only was the percentage of total refuse cut down from 20 to 8 per cent., but the number of slate pickers on the picking belts was reduced by half.

The particular sampling device as installed at Banner (shaft equipped with the Ramsay revolving dump), could not be installed in connection with all tipples. Consequently, Mr. Ramsay has worked out a device, for which he has applied for a patent, that will be adaptable to tipples equipped with horn or crossover dumps.

The method of handling the sample after it has been procured is practically the same as at Banner, but the method of obtaining it is entirely different. A series of small openings in the chute bottom is covered with movable plates controlled by levers conveniently arranged so that one man can operate them. This arrangement makes it possible to take several samples from one

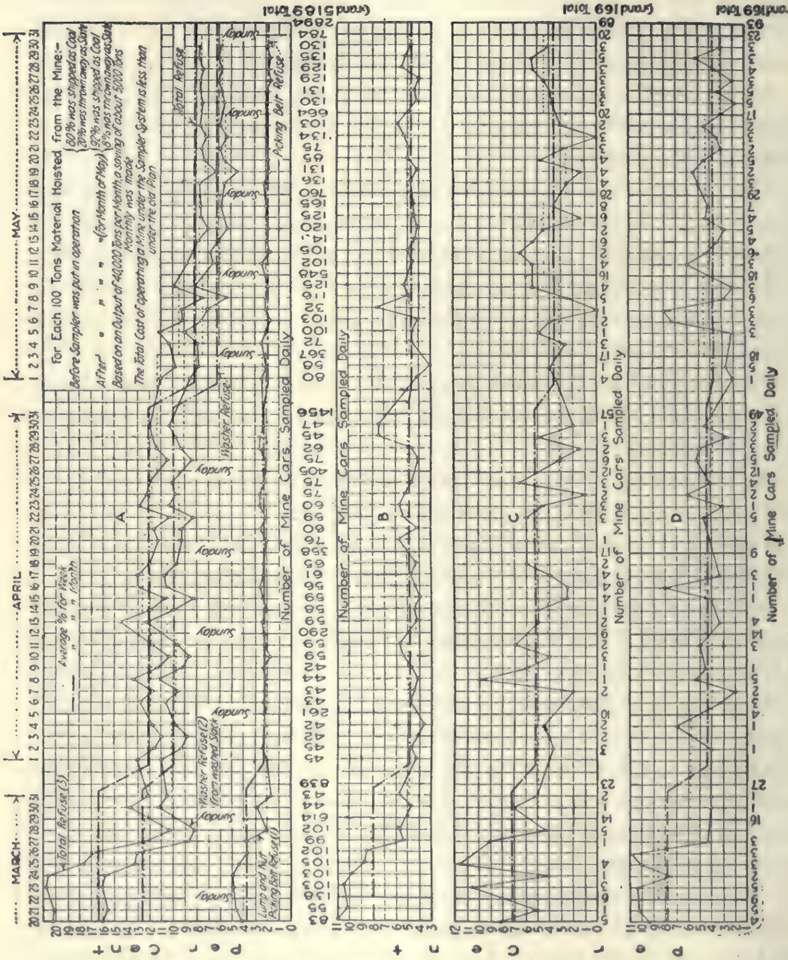

MARCH
APRIL
MAY
For Each 100 Tons Material Hoisted from the Mine:-
Before Sampler was put in operation
80% was shipped as Coal
20% was thrown away as Slate
After
92% was shipped as Coal
8% was thrown away as Slate
(for Month of May)
Based on an Output of 40,000 Tons per Month a saving of about 5,000 Tons Monthly was made
The Total Cost of operating a Mine under the Sampler System is less than under the old Plan
Average % for Week
" " " Month
Total Refuse (3)
Washer Refuse (2) from washed Slack
Lump and Nut Picking Belt Refuse (1)
Total Refuse
Washer Refuse
Picking Belt Refuse
Sunday
A
B
C
D
Per Cent
Number of Mine Cars Sampled Daily
Grand 5189 Total
Grand 169 Total

Table 6

car or several samples from a trip of cars dumped in rapid succession. Figs. 33, 34, 35 and 36 show different views of this apparatus.

This machine, with no attention from, or delay to, the dumper, and therefore without reducing the usual tipple dumping capacity, automatically takes individual samples of 100 to 200 lbs. run-of-mine coal from each mine car sampled, the samples being

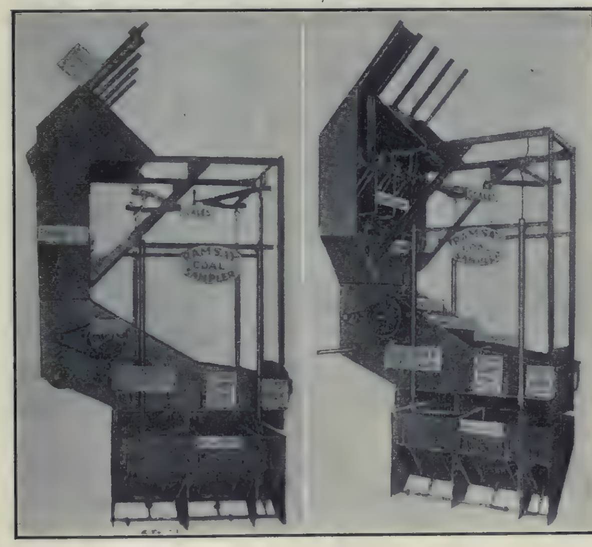


Fig. 33 Fig. 34

Ramsay Mechanical Sampler for Cross-over dumps

taken from the stream of coal as, and when, it flows from the mine cars. A record of the miner's check taken from each mine car sampled is kept. This record shows the percentages of rock, coal and slack found in each sample. The sample taken from the mine car is assumed to be of the same quality as that of the entire car, just as is the case with sampling railroad cars. In this way the *mine management knows every day exactly the quality of coal each and every individual miner is sending out.* Three men, one operator and two pickers, do everything connected with taking the samples, from a large proportion of the total mine cars dumped daily in addition to picking, weighing

and recording the results. The operator, stationed on the tipple floor, sees the dumping of the mine cars and at the same time observes and controls the operation of the machine taking the

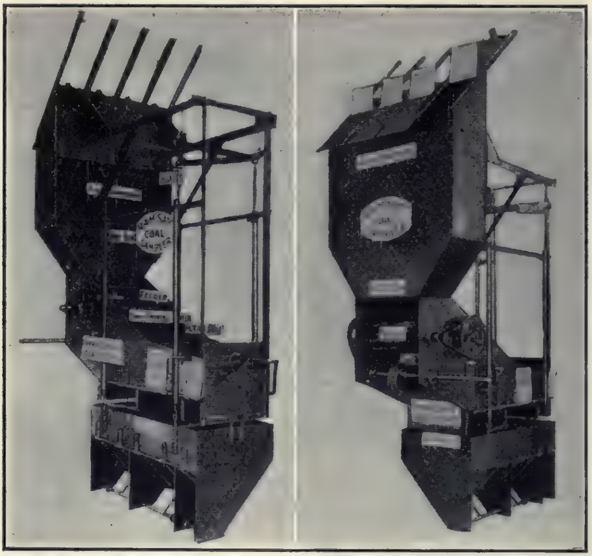


Fig. 35 Fig. 36

Ramsay Mechanical Sampler for Cross-over Dumps

samples, weighing and recording the component parts of the treated sample. The pickers do nothing but pick the samples. This machine has a capacity of taking and treating samples at the rate of one per minute.

CHAPTER XII

INTERMEDIATE UNITS BETWEEN THE SCREENING PLANT AND THE WASHERY

A. Raw Coal Storage Bin

A raw-coal storage bin by all means should be included in every coal washery, and this should be made as large as possible for the following reasons:

1. Every interruption in hoisting coal will stop the washery if a certain reserve cannot be supplied during such periods.

2. The foregoing holds true for an interruption in the operation of the screening plant.

3. If the operation of the washery is interrupted, the presence of a raw-coal storage bin will permit the screening plant to be run until the raw-coal bin has been filled. Otherwise the screening plant must be shut down and in connection therewith the hoisting of coal must cease and the working of the whole mine must be stopped.

4. A coal mine does not deliver the coal regularly during the whole day. In the morning the hoisting is rather slow and speeds up until the middle of the day. It is apt to slow down toward the evening. For the proper operation of a washery a regular supply of coal is of the greatest importance. A good sized raw-coal bin permits drawing off of some coal left over from the preceding day during the period of slow hoisting and the filling up of the bin when more coal is hoisted than the washery can handle.

5. If on account of heavier hoisting than figured upon or on account of insufficient capacity of the washery more coal is mined than the washery can take, a large raw-coal bin will make it possible for the washery to consume the daily output of the mine by working overtime.

In consideration of the reasons just enumerated, the raw-coal storage bin demands the fullest consideration as it is an important equalizer between the mine, the screening plant and the

washery. If it is not possible to build a sufficiently large bin between the screening plant and the washery, it will become necessary to build one or more reserve bins at some convenient place. Conveyors must be installed to carry the coal between these bins and from them to the washery. The different units between the screening plant and washery are the conveyors from the screening plant to the storage bin, the storage bin proper and the conveying system from the bin to the washery.

In the above it has been assumed that the mine and the washery are located in close proximity. If, however, the washery, as is often the case, is located at some distance from the mine or if a central washing plant receives the coal from a number of mines, two equalizing units are required, one at the mine between the screening plant and the railroad cars and the other between the railroad cars and the washery. If sufficient room is at disposal and a regular supply of railroad cars is assured, a railroad yard sufficiently large to hold enough cars to load out at least an 18-hr. output of the mine will be a more economical proposition than a large bin with the necessary elevating and conveying machinery. But with this arrangement an absolutely regular supply of railroad cars must be guaranteed. This is, however, highly problematical, as the possibilities of such an ideal supply of railroad cars are remote.

To arrive at the proper arrangement of the different units it is necessary to form a correct idea of the most advantageous location and elevation between the screening plant and the washery. The following facts must be considered:

The elevation of the screening plant is fixed by the elevation of the railroad track in the loading yard under the tipple. To load the coal directly from the screens into the railroad cars in the most efficient manner the coal should neither be elevated by separate machinery nor should it drop from too high a point. The elevation of the rails under the tipple are the base from which the elevation of the screening plant must be determined. In a screening plant the use of elevators can be easily avoided, but in a washery conditions are different. The coal must pass over a number of different pieces of apparatus and elevators cannot be entirely avoided.

It has been previously stated that modern washeries are de-

signed with the point in view of avoiding as far as possible the use of numerous small elevators and to place the first units of a washery at such a height that the materials can be conveyed either by gravity or in sluiceways with water through the whole plant. On account of this method of construction it becomes necessary to elevate the raw coal from the screening plant to the washery at a considerable height.

Because the raw coal travels from the screening plant to the washery by way of the raw-coal bin it will be necessary to determine how this bin can be located to the best advantage and so as to make the carrying of the coal as economical and efficient as possible. A raw-coal bin of even a few hundred tons' capacity requires a heavy supporting structure and therefore it should not be located any higher than absolutely necessary. The conclusion is thus reached that the heaviest elevating should not be done between the screening plant and the bin but between the bin and the washery.

Some designs do not show a proper bin at all but only an arrangement to deposit the raw coal on the ground, with maybe a low retaining wall on both sides to keep the coal from spreading too far. These walls can also be used to support the loading conveyors. The coal is recovered from this pile by a conveyor running in an underground tunnel.

For the elevation of great quantities and the required uniform delivery steep bucket elevators have proved themselves especially well adapted. Skip hoists cannot be considered, because the delivery is irregular and intermittent. For these reasons it is advantageous to locate the raw-coal bin close up against the washery at the ground level. If we now consider that the coal is delivered from the screens at a slight elevation above the track level, and that the top of the raw-coal bin, on account of its required large capacity, is at a much higher elevation, a normal arrangement of the units between the screening plant and the washery will be as follows: Elevating or conveying machinery to overcome slight differences in height between the screening plant and the raw-coal storage bin and elevators to overcome a considerable difference in height for feeding the washery from this bin.

For the conveyance of coal to the raw coal bin scraper and belt conveyors are admirably adapted.

Scraper conveyors are well adapted for steep grades and short distances. Their construction is simple and they have large capacity with relatively small power consumption. Belt conveyors are also advisable because they carry the smaller sizes of screened coal efficiently. The question to be solved is, which of these two types of conveyors fulfills the conditions to the best advantage?

Belt conveyors are theoretically well adapted for this purpose. The delivery chutes from the screens deposit the coal upon the belts in the best possible manner. The hoppers under the screens act as equalizers and permit uniform loading of the belts. The discharge of coal from the belt into the bin is carried on easily and the coal is transported without degradation. But on the other hand belt conveyors are rather expensive and the belts require frequent renewals.

The main item of expense in the upkeep of belt conveyors is that of the renewal of the belt. With ordinary care and attention a good grade of conveyor belt should last from two to five years. The belts may have a speed of from 200 to 600 ft. per minute and the capacity depends upon the width and speed. The following table gives capacities of conveyors usually employed.

CAPACITIES OF TROUGHED BELT CONVEYORS

Material—Coal, weight 50 lb. per cubic foot

	Speed 200 ft. per minute.		Speed 400 ft. per minute.		Speed 600 ft. per minute.	
Width of conveyor belt.	Largest size of cube which can be carried. Inches.	Tons per hour.	Largest size of cube which can be carried. Inch.	Tons per hour.	Largest size of cube which can be carried. Inch.	Tons per hour.
12	2	6	½	16	¼	22
16	3	16	1	34	¾	50
18	4	20	1½	45	1	70
20	5	30	2	60	1	100
24	6	50	3	100	1	190
30	7	100	4	200	2	360
36	9	180	6	340	2	600

TABLE 7

Fig. 37 shows a scraper conveyor and Fig. 38 a belt conveyor installation.

Scraper conveyors are comparatively cheap, quite durable,

and the separate parts can be easily and cheaply replaced so that they are better adapted for rough treatment. But they grind up the coal so that the choice between the two types of conveyors depends a great deal upon the nature and size of the material to be conveyed. Soft friable coals require belt conveyors, especially if the small sizes are of little value. To a hard coal that does not shatter much or to a coking coal where fines are not

Fig. 37. Scraper Conveyor

objectionable, scraper conveyors will be better adapted. But the scraper conveyors use more power than the belt conveyors so that the cost of energy is another consideration that must be taken into account in making the proper selection of the most economical type of conveyor.

Scraper or belt conveyors are not only used for the filling of the raw-coal bin but are also employed for the conveyance of the different materials through the washery, and especially for the

filling of the washed coal bins, which are usually arranged in a series of separate bins set in a row. To fill these bins by means of scraper conveyors it is only necessary to put in openings provided with sliding gates in the bottom of the conveyor trough, at the proper points.

Belt conveyors can be easily equipped with trippers, which will permit the discharge of the coal at any point, or fixed discharge stations can be built into the conveyor. The trippers can be either hand-operated or they can be made automatic and

Fig. 38. Belt Conveyor

self-reversing. By locating movable stops on the track rails the coal can be discharged either over the whole length of the bin or over any part of it. For bins which are located at right angles to the general flow of material, shuttle conveyors can also be used to advantage.

Which one of the arrangements should be employed depends entirely on the type of the bin. Generally speaking, belt conveyors on account of their light weight and their adaptability to almost any condition are to be used for long distances and for fine coal if it is not too wet. For coarse and wet coal and for short distances scraper conveyors are to be preferred. For

short horizontal conveying, shaking conveyors of the Marcus or Zimmer type can also be used to great advantage.

The Design and Construction of Raw Coal Bins. If the raw-coal bin is included within the main washery building the same material is used in the construction of both units. This is either timber, steel or reinforced concrete, or in some rare cases, cast iron. Raw-coal bins are built either rectangular or round.

Fig. 39. Tripper for Belt Conveyor

Rectangular bins are more expensive in construction but have a greater capacity per square foot of ground space occupied than have circular bins. Rectangular bins permit also a more perfect arrangement for loading and unloading apparatus than do round ones, especially if the necessary capacity increases.

The capacity of the raw-coal bin depends upon the output of the mine and should be at least as large as the daily production. Bins with a capacity of 4,000 tons have been constructed and some of the latest designs show bins with 6,000 tons capacity.

Fig. 40 is the photograph of a raw-coal bin of 4,000 tons' capacity, built of re-inforced concrete, and Fig. 41 gives the general drawing of the same bin.

Fig. 40. 4,000 Tons Raw Coal Bin, built of Re-inforced Concrete

B. Feeding the Washery from the Raw Coal Bin

Requirements. The mechanical appliances for supplying the washery with raw coal are of the greatest importance. The continuous and regular operation of the washery depends entirely on a steady coal supply; therefore, the strictest specifications should be applied for the design and construction of these appliances.

The capacity must be fully equal to that of the washery. It must be considered that elevators handling large tonnages require large, heavy buckets. On account of the size of the weights to be hoisted and the height to which the coal must be elevated, failures of the chain are disastrous and repairs become difficult and take up much time. For this reason it is preferred to use in large plants two elevators.

On the other hand the general arrangement and the space available permit the installation of only one raw-coal bin. This makes the installation of more than two elevators almost impossible on account of the lack of room at the bottom of the bins. The conditions at the discharge end of the elevators are similar.

As a usual thing only one unit is provided to receive the raw coal, and economic reasons demand the concentration of the flow of coal through the washery. Therefore we must seek absolutely

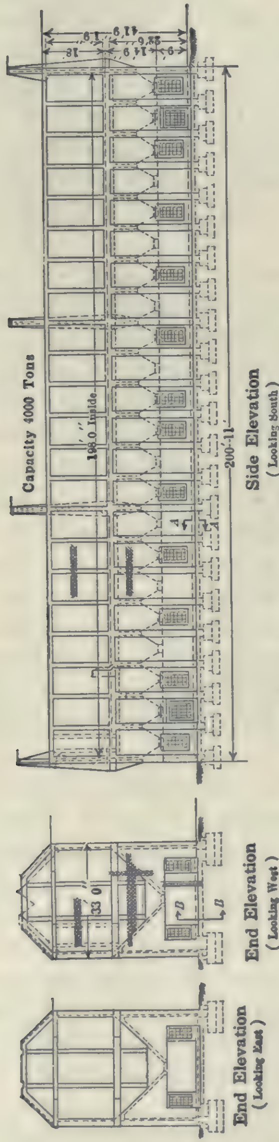


Fig. 41. 4,000 Tons Raw Coal Bin

reliable operation of the elevators. This can only be obtained by using the best of materials, by ample dimensions of the carrying members and by the best workmanship. First cost cannot be considered if we take into account the increase in cost of operation caused by repairs and interruptions.

But even with all these precautions it is advisable, whenever possible, to have a complete spare elevator on hand. In case of a wreck or the collapse of an elevator repairs take a long time, and for this reason a spare elevator ought to be in place for immediate use.

If these precautions are required for continuous operation, there remains still the necessity for a regular and uniform supply. This is of the utmost importance for the efficient working of a washery. On account of the existing conditions, which require the elevating of coarse-grained material at a steep angle to a considerable height, absolutely continuous discharge can hardly be accomplished. But the continuous bucket elevator comes nearer to fulfilling the conditions than any other apparatus.

Bucket Elevators. Bucket elevators are used in coal washeries for various purposes. The most important of these are the following: Supplying the washery with raw coal; dewatering the washed coal and elevating it into the washed coal bins; supplying the rewash jigs; dewatering the sludge; dewatering the secondary product (boiler house coal) and elevating it to the boiler house coal bin; dewatering the refuse and elevating it into the refuse bin.

The design and construction of elevators depend upon the material to be handled. To avoid repetitions the main types of elevators used for the different purposes will be described under a common head.

Most of the elevators are constructed with a two-strand steel-link chain. The chain links and the connecting bolts and rods ought to be fabricated out of the best medium carbon machinery steel. Small elevators have flat links, but for heavy elevators links with upset ends are to be preferred. Under ordinary conditions and for dewatering elevators, buckets are fastened to the chain at every other link. For raw-coal elevators buckets are provided at every link, making it a continuous bucket elevator.

Fig. 42 gives the working drawing of a continuous bucket ele-

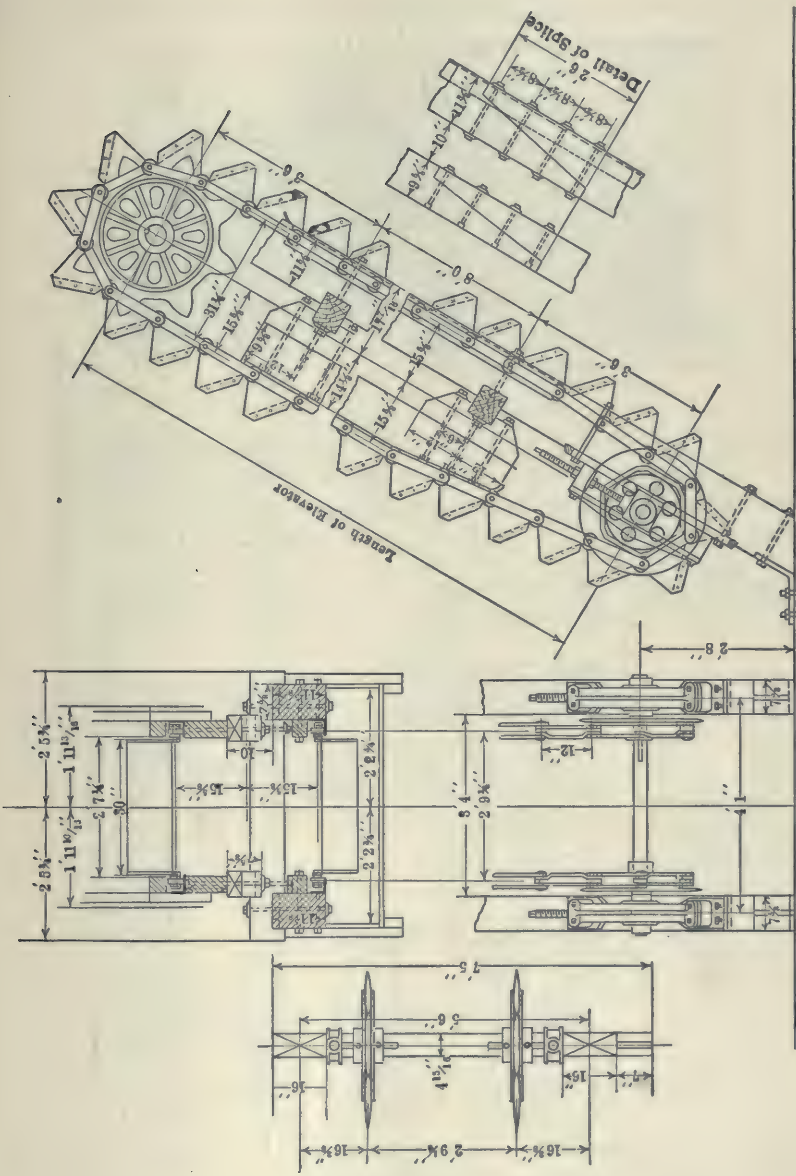


Fig. 42. Continuous Bucket Raw-coal Elevator

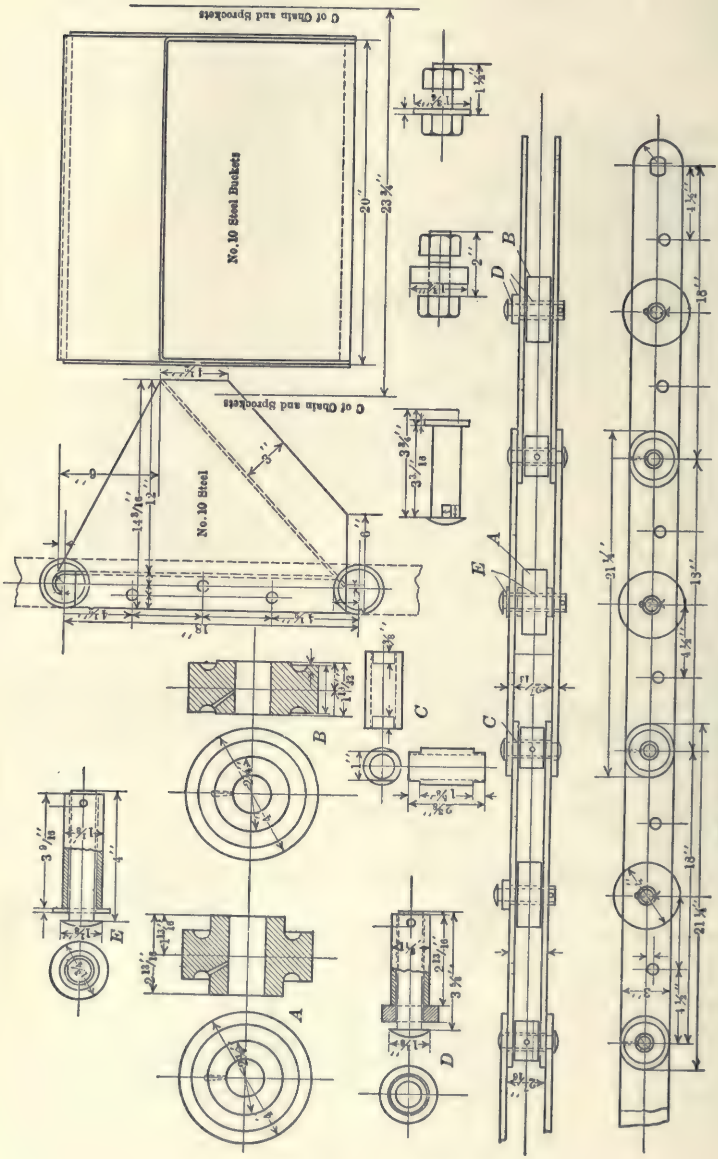


Fig. 43. Bucket and Chain for Raw-coal Elevator

vator for raw coal and Fig. 43 the details for the bucket and the chain. In Fig. 44 a bucket with perforated sides, as used

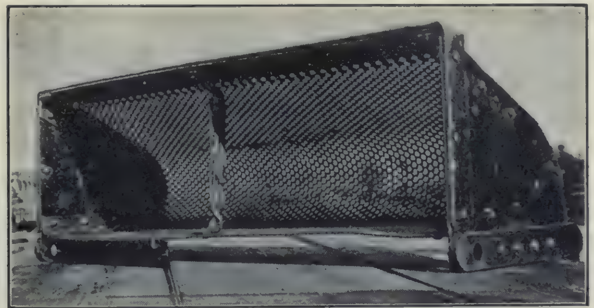


Fig. 44. Washed Coal Elevator Bucket

for washed coal and refuse, is shown, while Fig. 45 shows buckets and chains of a "Lührig" dewatering elevator.

Buckets are made from steel plates, securely riveted to the end plates and provided at the top edges with stiffening bands.

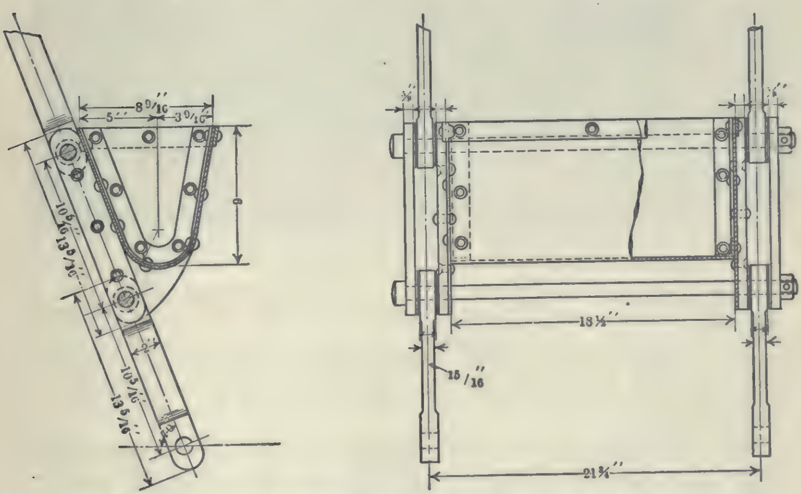


Fig. 45. Bucket and Chain for Lührig Dewatering Elevator

Wide buckets have also a stiffener in the middle to prevent bulging out of the sides. The ends of the buckets are fastened to the

sides with angle iron or, in some instances, the ends are made of malleable iron. Malleable-iron buckets or those pressed from one piece of steel plate are seldom used. Dewatering elevators have buckets with sides and ends made out of perforated plates. The size of the perforation must be in proportion to the size of the coal handled.

The elevator chains at the top are carried over sprocket wheels or head drums. On the lower end foot drums are universally used. Square, hexagon and octagon drums are employed, de-

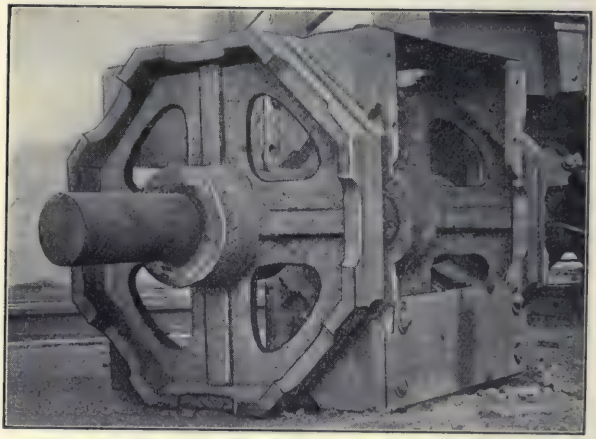


Fig. 46. Octagon Head-drum for Lührig Elevator

pending on the pitch of the chain links. Octagon drums can be used with short pitch chain, whereas those of long pitch require square drums. The pitch of the chain links varies from 8 to 18 inches.

An octagon head drum with discharge plates is shown in Fig. 46, and Fig. 47 shows the upper part of a washed coal elevator.

The take-ups are generally placed at the foot of the elevator and only on small elevators are the take-ups placed at the top. Head and foot drums are either made of steel or have steel wearing plates. The chains are guided between angle irons which ought to be protected by wearing plates.

Fig. 49 is an illustration of a single take-up. For washed coal

and refuse elevators, where the take-up is under water, the take-up screw and its nut are made of bronze.

Elevators are usually driven through a train of gears or by a sprocket or silent chain drive. Belt drives should not be used on account of the danger of slipping. The gear wheels should be of steel while for heavy elevators manganese steel gears ought to be specified.

To prevent the running back of an elevator, when the power

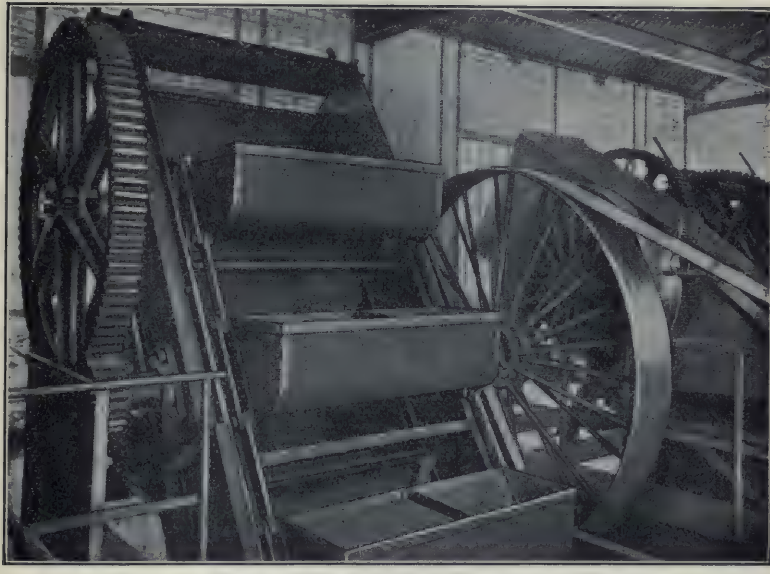


Fig. 47. Head of Washed Coal Dewatering Elevator

goes off or when the belt slips, various forms of hold-backs are made. The simplest construction uses a pawl and ratchet wheel. Another type illustrated in Fig. 50 has the pawl mounted on a split sleeve, which is clamped on the hub of the driving pinion by means of four bolts, fitted with compression springs. These springs provide sufficient friction to make the pawl tend to revolve with the pinion. A stud projecting from the pawl strikes a stop and prevents its turning. The instant the power goes off, however, and the pinion starts to reverse, the pawl turning back with the pinion throws its tooth into the teeth of the gears

and thereby locks the entire mechanism. Both of the above hold-backs have the disadvantage that the motion of the elevator is arrested suddenly.

The roller hold-back illustrated in Fig. 51 acts somewhat

Fig. 48. Washed Coal Elevator

smoother. It is designed on the same principle as a coaster brake of a bicycle.

A still better type of hold-back uses a band brake which is loose as long as the elevator moves in the right direction, but as soon as it commences to run backwards, this brake is tightened and stops thereby the reverse motion gradually and effectively.

The framework supporting the chains may be made of steel

for the raw-coal elevators, but for dewatering elevators timber frames are to be preferred. The head and jack shafts ought not to be supported on the elevator frames, but on a separate supporting structure. This is advisable in order to facilitate re-

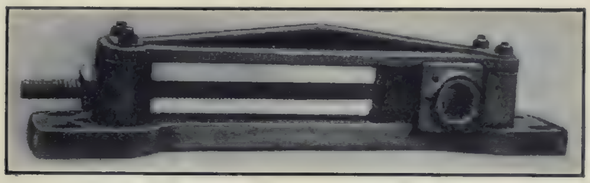


Fig. 49. Single Take-up for Coal Elevator

pairs and to keep the gears in better alignment. The size of the bucket elevators varies considerably. The elevators for heavy tonnage are massive and heavy, and must therefore run slowly in order to prevent rapid wear. Dewatering elevators also must

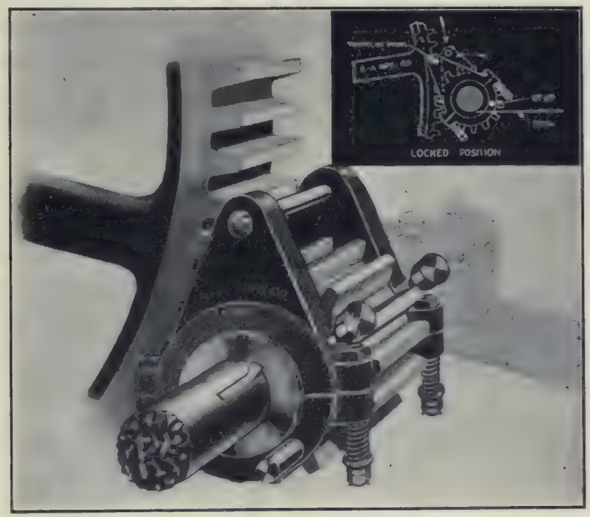


Fig. 50. Hold-back for Elevator

operate at a slow speed to permit the draining out of the water before the buckets reach the discharge point.

Dewatering elevators must be inclined to such a degree that the water running out of one bucket will not drip into the one

next lower. Raw-coal elevators could be installed vertically, but this arrangement would require too much room at the head as well as at the foot end. The inclination of a raw-coal elevator depends entirely upon the room available. The speed of raw-

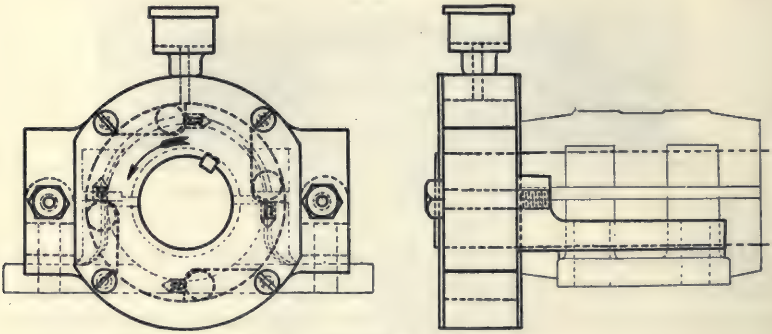


Fig. 51. Hold-back for Elevator

coal elevators ought not to exceed 100 ft. per minute while dewatering elevators should not be run faster than from 50 to 60 ft. per minute. The maximum capacity of elevators in coal washeries is about 200 tons per hour.

TABLE GIVING GENERAL DIMENSIONS AND CAPACITIES OF RAW COAL AND WASHED COAL ELEVATORS

	Raw Coal Elevators	Washed Coal Elevators
Height in feet	30–135	45–120
Width in inches	12– 50	18– 60
Number of buckets	25–200	30–100
Inclination in degrees	40– 80	40– 60
Capacity in tons per hour	25–250	15–100
H.P. required	5– 70	12– 35
Dewatering effect in percentage of water remaining in the coal	......	13– 10

TABLE 8

CHAPTER XIII

CLASSIFYING OF THE FINE COAL

The coal discharged from the raw-coal elevator at the highest point of the washery must be separated from its impurities and screened into the different sizes demanded by consumers. The ways and means employed in this process vary according to the system of washing followed. As all the bituminous coals are similar in nature, it becomes necessary to study the different points involved before we can follow clearly the development of the different methods used.

The first question is: Shall the raw coal as a whole be subjected to washing or will it be better to screen out the fines? This main question can be divided into several parts, because different conditions require different solutions. The first subquestion is: Is it possible to improve the fines by washing? This can be answered in the negative with all possible assurance. The consideration, however, as to how fine the coal can be to be successfully washed is still disputable.

Laboratory investigations and results of actual operation give largely different limits. It can safely be stated, however, that coal passing through a 20-mesh screen will not show any marked improvement by washing. However, it is not possible to give an absolutely binding limit for all sorts of coal. A correct decision in regard to the permissible fineness of the coal to be washed can only be arrived at through accurate and reliable tests.

Thomas James Drakeley made some tests to determine whether any advantage would accrue from removal of the dust from the raw coal previous to washing, which gave the following results: The sample of raw coal was screened over a series of screens having 30, 60, 90 and 120 meshes to the inch, respectively. The ash content of the powders were determined and compared with the ash content of the corresponding dried slime. In all cases

the fine coal removed from the raw coal yielded less ash than the settlings. An example is given in the following table:

Ash Content of Raw-Coal Dust and Slime

Raw Coal Powder screened Through	Over	Percentage of Ash	Slime from Washed Coal. The whole of the slime passed through a sieve with 120 meshes to the inch. Percentage of Ash
30 mesh	60 mesh	23.09	
60 mesh	90 mesh	22.48	26.35
90 mesh	120 mesh	20.50	
120 mesh	....	17.71	

Table 9

It is obvious, therefore, that during the washing process some of the impurities disintegrate and pass away with the finest coal. The settlings are in consequence inferior to the dry coal-dust. Hence, it would appear to be economical to remove the dust previous to washing. This dust could be mixed with the washed coal without unduly diminishing its value. The settlings would be composed of a larger proportion of ash-yielding constituents and could be regarded justly as refuse.[1]

If it has been proved that the fines can not be improved by washing, the next question is: Is it possible to screen out the fines in the dry state? The condition of the coal in the mine will primarily determine this question. If it comes from a so-called dry mine, dry screening is probably possible, but if the coal comes out of a wet mine, or contains more than from 5 to 6 per cent. of moisture, all efforts at dry screening will fail.

The third question is: Are the advantages gained from the screening out of the fines sufficient to justify the cost of installation and operation of the necessary machinery? The considerations governing this point are as follows: (a) If coal is to be sized before washing, the screening operation will without doubt be more perfect. (b) Dust mixed with water becomes slime, which hinders the jigging process. If the dust has been eliminated, the jigs will deliver a refuse more nearly free from good coal and therefore work with greater efficiency. (c) If the im-

[1] From "Coal-Washing: A Scientific Study," by Thomas James Drakeley.

purities in the raw coal contain fireclay, which dissolves freely in the water, and on the other hand the coal dust is comparatively clean, the fireclay and the dust will be mixed together in the jigs and the resulting fines will be high in ash. The fines in this case will be of better quality if screened out before washing. (d) If the fines themselves contain fireclay, the wash water will become thick and difficult to clarify, requiring large and expensive clearing basins. (e) If the dust is sufficiently low in ash it can be mixed with the washed coal without increasing the ash in the final product. This method will also facilitate the difficult problem of dewatering the fines. (f) The possibility of reducing the ash in the washed product without increasing the loss of good coal, through screening out the dust, permits the addition of dust higher in ash than would be possible if the dust were not thus screened out.

In the light of the foregoing considerations, if heed is given to the fact that the removal of the fines is comparatively simple, the question of dust separation can be answered as follows: Except in cases where the raw coal contains too much moisture or where the nature of the material is such that little dust or sludge is produced, the installation of a dust separator ahead of the jigs is to be recommended.

The second question in regard to the proper method of washing is: Shall the coal be sized before or after washing? Close sizing before washing is not necessary. Only with a coal that is difficult to wash and one that is at the same time hard and not liable to make a great amount of fines, is sizing before washing to be preferred. Otherwise the sequence of operations will depend upon the nature of the coal—that is, how closely it should be sized or whether it should be washed unsized. Therefore, in washing plants we find at present the following main methods of procedure: (1) Sizing before washing, and the employment of separate jigs for each size. (2) Preparatory separation into two or three grades in addition to dust, and separate jigs for each of the three or four sizes. (3) Sizing into coarse and fine coal only, and separate jigs for both sizes. (4) Jigging of the unsized raw material with subsequent sizing into coarse and fine coal and rewashing of the fines. (5) Washing of the unsized raw coal without any sizing or rewashing.

With types 2 to 5, the final sizing of the coal for market is performed after washing. Type 5 is used for coking coals, and then only if the coal is easily washed.

Considering that not every washery is provided with a dust-collecting plant, and that the coal is sized either before or after washing, the required apparatus may be classified in the following order: Dust separating and collecting machinery, sizing machinery, washing machinery.

Dust Removal. To separate the dust at once from the total raw coal would give only imperfect results. Therefore, it is desirable to screen the coal at first into two sizes besides the lump—a coarse product from ⅜ in. to 3 in., and a fine coal from ⅜ in. to dust.

A plant for the separation of dust should screen out in as perfect a manner as possible all the dust up to a previously determined size without carrying away particles of coarser coal; because, if part of the dust remains in the coarse coal, the intention of facilitating the jigging and avoiding cumbersome settling basins will not have been fulfilled. On the other hand, if coarse coal goes with the dust some of the material which can be improved by jigging will not get the benefit of this improvement. Therefore, the fundamental principles are as follows: The utility of a plant for screening out the dust is in direct proportion to its perfect removal of dust containing no coarse coal.

Dust can be removed either on screens or by means of an air current. Screening appears theoretically preferable because the size of the perforations in the screen plates determines the largest size of particles that will pass through them. Failures encountered with the earlier installations were caused by the difficulty in keeping the perforations clear. This trouble, however, was overcome by the use of vibrating screens.

One great disadvantage of a screening plant for dust removal lies in the fact that such a plant is noisy, subject to frequent repairs, and that any air-tight inclosure for it is expensive and prevents the inspection of the moving parts. A dust separator using air currents works noiselessly and has no moving parts except the exhaust fan. It is also easy to inclose this type of apparatus in an air-tight casing, which is not objectionable because no moving parts requiring repairs are inclosed. With

an air separator, however, it is not possible to get perfect separation in regard to sizes; some coarse material is always carried away with the dust or some dust remains in the coarse coal. In addition to a careful selection of the apparatus, its constant con-

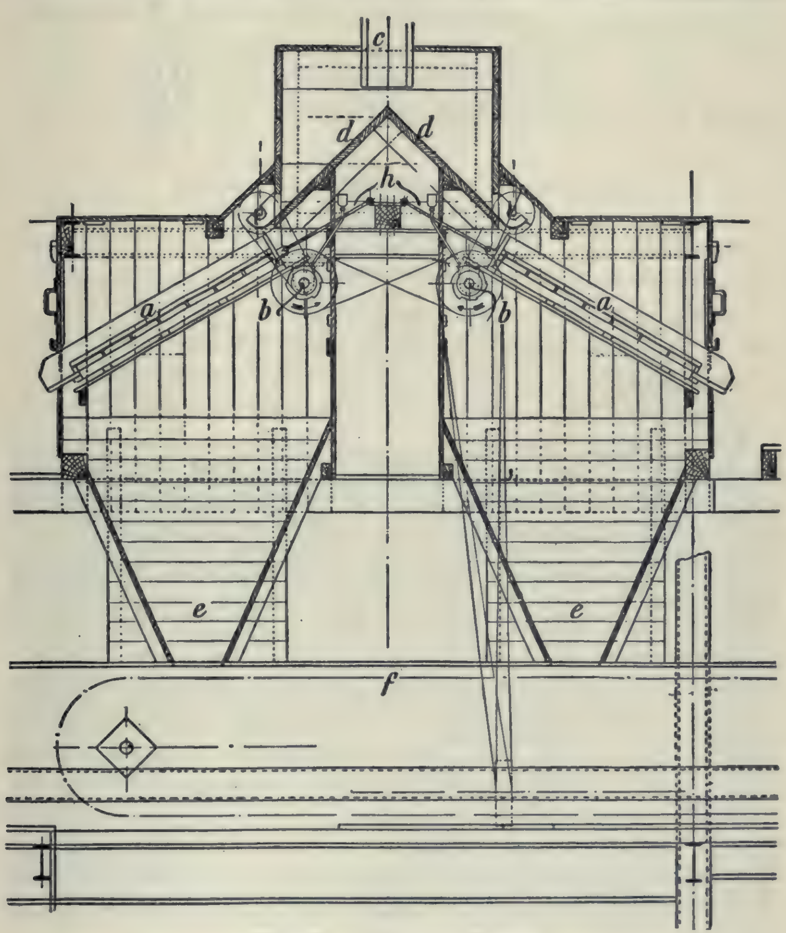


Fig. 52. Vibrating Screen

trol and adjustment are required to insure satisfactory results.

Fig. 52 shows a vibrating screen as used in Europe for the screening out of dust from coal.

The screen frames are fastened with wedges in an inclined

box "a." The screen itself is a fine mesh brass-wire cloth. The vibrations are caused by a shaft "b" having multiple cams and are uniformly transmitted over the whole screen by wooden springs "h."

The coal passes through the chute "c" and over the hog-back "d-d" on the screens. The dust is collected in the hopper "e-e" and can be carried away by the belt conveyor "f." The screens are inclosed in a dust tight casing. This apparatus can

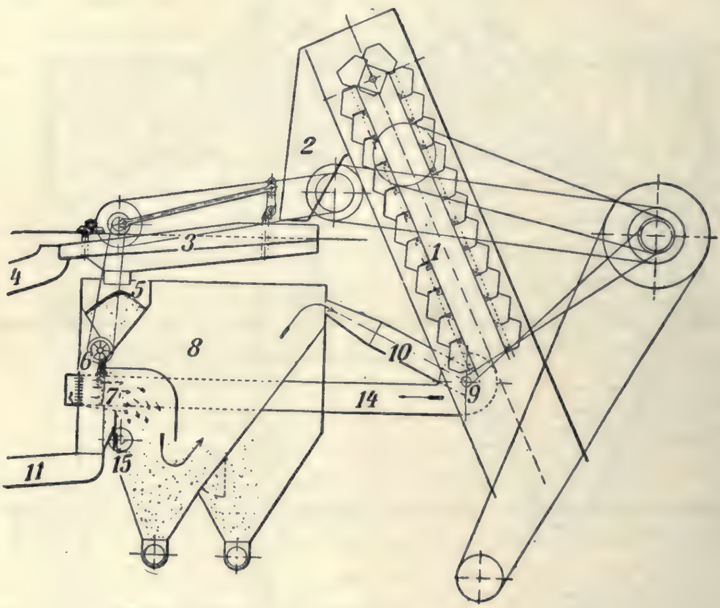


Fig. 53. Dust Collecting Plant. Elevation

remove dust finer than 3/32 in. if the coal contains from 4 to 5 per cent., and dust finer than 1/32 in. if the coal contains from 2 to 2½ per cent. of moisture. Screens 30 in. wide by 5 ft. long can handle from 2 to 4 tons of coal per hour. This small capacity would require a great number of screens to handle the quantities necessary for a modern coal washer.

A dust collecting plant in connection with a sizing screen is illustrated in Figs. 53 and 54.

The elevator "1" discharges the coal over the chute "2" on

the screen "3," with ⅜ in. round perforations. The oversize goes to the sluiceway "4" and the undersize into the hopper "5." The revolving feeder "6" carries the fine coal in a uniform stream across the slot "7." A current of air, coming

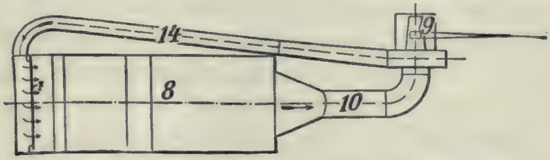


Fig. 54. Dust Collecting Plant. Plan View

through the pipe "14" passes through the coal. The coarser coal drops into the chute "11" and the dust is blown into the hopper "8" where the coarser particles are deflected by a baffle plate. The finer dust collects against the inclined wall of the hopper and can be discharged through a gate in a second hopper, if it is desirable to make two sizes of dust. The cleaned air re-

Fig. 55. Dust Collecting Plant

turns through a pipe "10" to the exhaust fan "9." Fig. 55 shows a photograph of a similar installation.

The Use of Dust. The use to which the dust should be put is determined by the nature of the coal, the amount of ash and

the method of collecting the dust. With a coking coal, dust can be mixed with the washed fuel if the ash content will permit. This is the simplest method of dust disposal, because it helps in the dewatering of the washed coal. If the ash content is high, at least a portion can be mixed with the washed coal.

If the dust, however, is excessively high in ash it can be further treated in connection with the sludge, or it can be used as fuel under a boiler or in cement kilns, or it can be made into briquets. With fuel coal, the dust can be either briquetted or used under boilers; and if it is very high in impurities a considerable amount of it must be thrown away.

C. Sizing of the Coal

Sizing of coal can be divided in two groups of processes: (1) Sizing as a preparatory process for the jig work, and (2) sizing as a subsequent process after jigging to produce the proper grades demanded by the market. In both instances the same types of screens can be used and the difference exists only in the following details:

(a) In the preparatory sizing fewer screen plates with different size perforations are required on account of the fewer sizes demanded.

(b) The two processes demand a different arrangement of the screens. In the first case the screen products are fed to the jigs and in the latter case the different sizes are discharged directly into loading bins.

(c) The preparatory sizing is a dry screening process only. The sizing after washing is at the same time a dewatering process.

Preparatory Sizing. Preparatory sizing is only a preliminary process; the final sizing takes place after washing. The sizes made in preparatory sizing depend upon the character of the impurities and upon their amount in each size. A typical example is shown below:

	No. 1	No. 2	No. 3	No. 4	No. 5
	1	2	3	4	5
I. Group	$1\frac{1}{2}''-3''$	$\frac{1}{2}''-3''$	$\frac{3}{8}''-\frac{3}{4}''$	$\frac{3}{8}''-3''$	$\frac{1}{4}''-\frac{3}{4}''$
II. Group	$\frac{3}{8}''-1\frac{1}{2}''$	$\frac{1}{8}''-\frac{1}{2}''$	$\frac{1}{4}''-\frac{3}{8}''$	$0-\frac{3}{8}''$	$0-\frac{1}{4}''$
III. Group	$0-\frac{3}{8}''$	$0-\frac{1}{8}''$	$0-\frac{1}{4}''$	.....	.....

Table 10

An exact sizing is not necessary, as the grading of sizes is only preliminary and within wide limits.

Sizing after Washing. The arrangement of screens depends upon the customary sizes demanded by the market, but no exact standards have been thus far established. In Illinois five sizes are customary, but no two washeries are producing exactly the same sizes. The range is as follows:

	No. 1 extra inches	No. 1 inches	No. 2 extra inches	No. 2 inches	No. 3 inches	No. 4 inches	No. 5 inches
Always under ...	3¾	3½	2¼	2¼	1½	⅞	7/16
Always over	2½	1¾	1⅜	⅞	⅝	3/16	0

TABLE 11

The operators of Williamson County, Illinois, have agreed to the following standard sizes:

	Through	Over
No. 1	3″ round holes	1¾″ round holes
No. 2	1¾″ round holes	1″ round holes
No. 3	1″ round holes	¾″ round holes
No. 4	¾″ round holes	¼″ round holes
No. 5	¼″ round holes	

TABLE 12

The percentage of each size as well as the amount of refuse contained therein are of great importance when considering the arrangement of a washery. It is therefore necessary to determine these percentages in advance, since they form the basis upon which the capacities of all the apparatus employed in a washery, such as screens, jigs, elevators and storage bins for the washed coal and the refuse must be calculated.

This percentage of the different sizes does not remain constant during the life of a mine. Small variations can be taken care of by figuring the capacities of the different pieces of apparatus as well as that of the bins somewhat larger than necessary. If, however, the percentage should vary considerably, it will be necessary to change the size of each group. Suppose that the screened coal from a certain mine gives, by making the sizes shown in column "2" (see Table 13), the percentages found in column "3." On account of a change in the character of the

coal these percentages are altered as shown in column "4." If the consumer will agree to it, it will be possible to get the same percentages for each size by changing the perforations in the screens as shown in column 5 (see following table).

1 Group	2 Size I	3 Percentage of Size I Per cent.	4 Percentage of Size II Per cent.	5 Size II
No. 1	3″ to 2″	18	14	3″ to $1\frac{3}{4}$″
No. 2	2″ to $1\frac{1}{4}$″	13	12	$1\frac{3}{4}$″ to 1″
No. 3	$1\frac{1}{4}$″ to $\frac{5}{8}$″	18	16	1″ to $\frac{9}{16}$″
No. 4	$\frac{5}{8}$″ to $\frac{3}{8}$″	18	20	$\frac{9}{16}$″ to $\frac{5}{16}$″
No. 5	$\frac{3}{8}$″ to 0	33	38	$\frac{5}{16}$″ to 0

TABLE 13

The importance of knowing the percentage of the different sizes for a correct installation of the different units in a washery can be shown in the following tables:

Coal	Lump Per cent.	Egg Per cent.	1 Per cent.	2 Per cent.	3 Per cent.	4 Per cent.	5 Per cent.	Dust Per cent.	Total Per cent.
I.	24	...	5	6	7	8	32	18	100
II. ...	24	9	7	12	11	9	28	..	100
III. ..	9	13.5	7.9	19.5	...	..	50.1	..	100
IV. ..	5	7.5	7.4	7.5	12.5	..	60.1	..	100

TABLE 14

For determining the size and number of jigs and the size of the bins the figures in Table 14 are not sufficient. The amount of impurities in each size and the yield of washed coal play an important part in the proper selection of the number of jigs and size of bins. Table 15 shows the percentage of coal I. in Table 14.

	Lump Per cent.	No. 1 Per cent.	No. 2 Per cent.	No. 3 Per cent.	No. 4 Per cent.	No. 5 Per cent.	Dust
Coal ...	93	92	91	88	84	80	72
Refuse .	7	8	9	12	16	20	28
Total ..	100	100	100	100	100	100	100

TABLE 15

A daily capacity of 3,000 tons figured on the above basis will give the following quantities:

	Lump	No. 1	No. 2	No. 3	No. 4	No. 5	Dust	Total
Total raw coal ...	720	150	180	210	240	960	540	3,000
Clean coal	669.6	138	163.8	184.8	201.6	768	388.8	2,514.6
Refuse	50.4	12	16.2	25.2	38.4	192	151.2	485.4
Total	720	150	180	210	240	960	540	3,000

TABLE 16

Tests have shown that the yield and amount of impurities in the washed coal can be obtained as shown in the first and second horizontal lines of Table 17. This gives with a capacity of 3,000 tons the quantities shown on the third and fourth lines.

	No. 1 Per cent.	No. 2 Per cent.	No. 3 Per cent.	No. 4 Per cent.	No. 5 Per cent.	Sludge Per cent.	Total
1. Yield in per cent.....	90	88	85	82	78	40	
2. Impurities in washed coal	3	4	6	7	9	15	
3. Washed coal in tons..	135	158.4	178.5	196.8	748.8	216	1,633.5
4. Refuse in tons.......	15	21.6	31.5	43.2	211.2	324	646.5
Total in tons.....	150	180	210	240	960	540	2,280.0
plus lump coal							720.0
Total							3,000.0

TABLE 17

Table 14 is used to determine the size of the screens if the coal is sized before washing. Tables 15 and 16 are used as a basis for designing the jigs. The third line of Table 17 shows the daily quantities of the washed coal and can be used for determining the size of the loading bins. It is, however, advisable to make the washed coal bins of equal size and large enough to hold sufficient coal to fill two railroad cars. Thus with five sizes we will get a washed coal bin of 400 tons' capacity divided into five compartments capable of holding 80 tons each.

If the coal is sized after washing, the above figures must be used for the screen dimensions instead of the figures in Table 14. Table 17 on the 4th line shows the daily quantities of refuse and these must be used to determine the size of refuse elevator and bins.

Screens. The demands made upon the screens used in coal washeries are as follows:

(1) *Exact Sizing.* This demand is required only for final screening. If the final screening is not exact complaints from

consumers and the cutting of standard prices are the results. Exact sizing will be secured by a proper type of screen and the correct size of the different screen plates. It is important to avoid a crowding of the screens, as this renders exact sizing impossible.

(2) *Avoiding Trituration.* A sliding motion of the material is most favorable to avoid breakage of coal. The exact sizing is, however, of such importance that screens imparting to the coal a jumping motion are often used, since they size accurately. If it is considered that, at least when the coal is to be sized after washing, the material handled, has been subjected in the elevators, and the jigs to appreciable abrasion, it can be readily seen that prevention of further breakage is not especially difficult.

(3) *Capacity.* It is only natural that each piece of apparatus will be used to its fullest capacity. Great care, however, must be taken to determine the limitations of the screens. The capacity of a screen is fixed by the accuracy of sizing, demanded by the consumer. To force a screen beyond this would be uneconomical.

A specification for a screening plant must contain a clear definition of what is understood by "capacity." An effort must be made to build the screen for as great a capacity as possible. In most cases one system of washing must correspond with one type of screens. The installation of several types would result in a highly complicated arrangement for delivering the materials from one piece of apparatus to another.

(4) *Assurance of Steady Operation.* The installation of a spare screening plant can not be recommended on account of the above named complications and the necessity of making the best use of the space at disposal. Consequently the screens must be built for uninterrupted operation, free from breakdowns and repairs.

(5) *Avoidance of Vibration.* The location of the screens, usually at the highest point of the washery, and the rapid motion required for exact sizing can by an incorrect or unsuitable construction cause a detrimental vibration of the whole washery building.

(6) *Possibility of Changing the Screen Plates.* Under cer-

tain conditions it may become advantageous to be able to change the size of the coal by putting in screen plates having different perforations. The construction of the screens should be such that this can be done quickly and easily.

(7) *Accessibility.* On account of the lack of spare screens, repairs must be made quickly, since every repair of the screening plant shuts down the whole washery.

Revolving or Shaking Screens. Practical experience has demonstrated that exact sizing can be equally well obtained with either revolving or shaking screens. The coal is handled more gently on a flat shaking screen, since the material here slides over the plates, whereas in a revolving screen the coal is carried part way up on the inside of the mantle and caused to roll back again.

Sufficient capacity can be obtained from both types. Shakers with the same screening area as revolving screens have a greater efficient area, because with revolving screens only the lower part (about ⅕) of the whole area is used efficiently. On the other hand the compact construction of a revolving screen permits the employment of considerably greater screening areas. Revolving screens give, on account of the uniform motion and simplicity of the driving mechanism, a greater assurance of uninterrupted operation than do shaking screens. Improved construction and careful design of the modern shaking screens have however, placed them on an equal footing with revolving screens in regard to continuous performance.

Vibration can be almost entirely avoided through the use of revolving screens. With shaking screens vibration can be reduced but not totally eliminated, through the use of balanced screens and flexible hanger rods.

Accessibility and rapid change of screen plates are difficult to obtain with revolving screens but offer no difficulty with shaking screens. Besides the above, we must consider the amount of power required, which is somewhat smaller for revolving than for shaking screens.

The above discussion shows that no universal decision can be reached. In condensing the different considerations the following axioms can be obtained:

Shaking screens are to be preferred if the possibility of chang-

ing the screen plates and the accessibility in case of repairs are to be considered of primary importance. If absolute assurance of continuous operation, absence of vibration and low power consumption are more important, revolving screens are to be recommended.

In Illinois[1] the sizing of raw coal prior to washing is carried on on 12 revolving screens and 2 shaking screens, and the sizing of the washed coal on 35 revolving and 20 shaking screens.

It has been previously explained (page 7) that the question of screening from fine to coarse or from coarse to fine has no fundamental importance, and that the space at disposal and the most

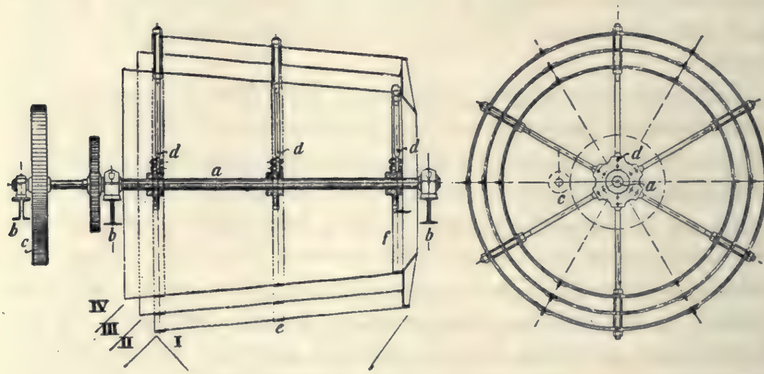


Fig. 56. Triple-Jacketed Revolving Screen

suitable arrangement are of greater importance. Screening from coarse to fine gives the advantage that the material is received on the screen plates having the largest perforations, thereby saving the finer mesh screens from much wear. This system of screening demands, with revolving screens a construction of concentric plates or the arrangement of separate screens for each size of coal, because the undersize from each screen must be further separated into additional different sizes. We have, therefore, the choice between a compact but inaccessible apparatus and a series of separate screens arranged at different levels. With shaking screens we meet the same conditions.

In screening from fine to coarse, screen plates with different

[1] "Coal Washing in Illinois," by F. C. Lincoln. Bulletin No. 69, Engineering Experiment Station, University of Illinois.

perforations can be placed in one mantle of a revolving screen or in one shaker frame. This makes the screens much simpler and more accessible. A limit is given by the required length of the screen, so that if a good many sizes must be made, a division into separate screen units is required which destroys simplicity. The use of shaking or revolving screen units with only one size of perforation is not to be recommended, since it increases the cost of the complete installation, which can be avoided. The

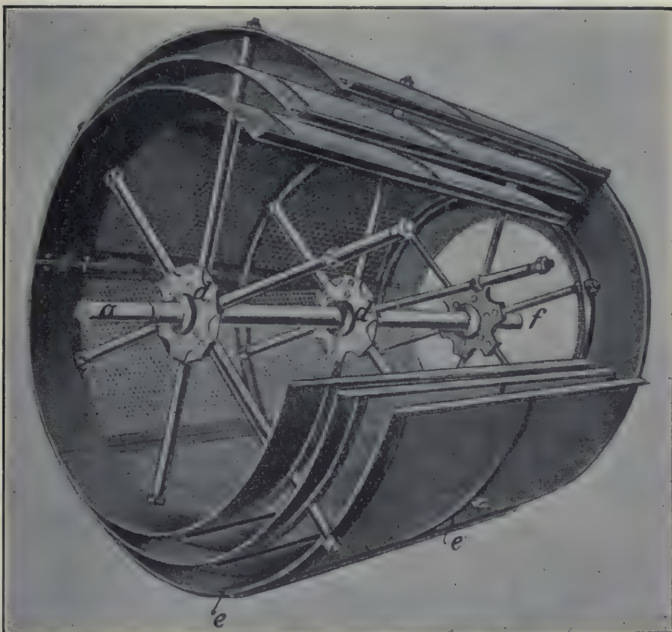


Fig. 57. Triple-Jacketed Revolving Screen

sizing from coarse to fine in concentric revolving screens or in multiple shaking screens is advantageous if a good many sizes must be made in the least possible space.

The sizing from fine to coarse in revolving or shaking screens having different perforations in one plane can be of advantage only if but a few sizes are to be made.

Types of Revolving Screens. Only concentric revolving screens will be here described. Single jacketed revolving screens are seldom used in coal washeries.

The shaft "a" rests in bearings upon supporting beams "b," but could with equal ease be hung from above. This shaft carries three spiders "d" having six arms each. These spider arms support the rings "e" which carry the screen plates. Coal enters the screen at "f." The coarsest size leaves the screen at IV and the finest at "I." N jackets make n + 1 sizes. The screen

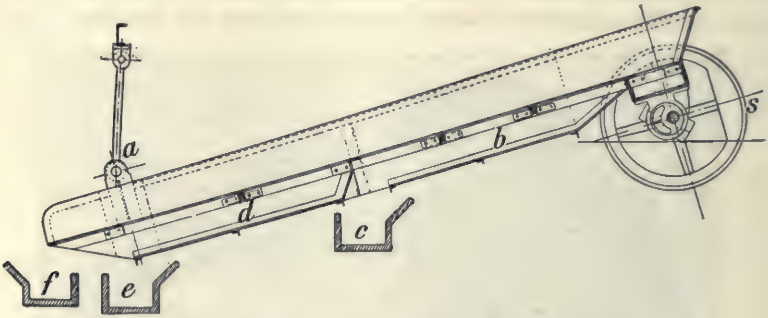


Fig. 58. Shaking Screen for Three Sizes of Coal

can be driven either from the right or left side by means of gears "c." The shaft may be omitted and the screen carried on rollers. Screens of the above type are in extended use and operate well.

Shaking Screens. Shaking screens are used mostly for screen-

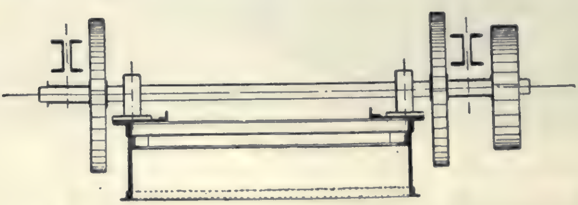


Fig. 59. Cross Section of Shaking Screen

ing from fine to coarse, since only a few sizes can be made on one screen. Figs. 58, 59 and 60 show a shaking screen making three sizes. Such screens can be used for the re-sizing of the washed coal and are usually installed on top of the washed-coal bins.

Fig. 61 shows such an installation. The washed coal from

3 in. to 0 in. is sluiced in the launder "a" onto the upper screen. All coal smaller than 1¼ in. passes with the wash water through

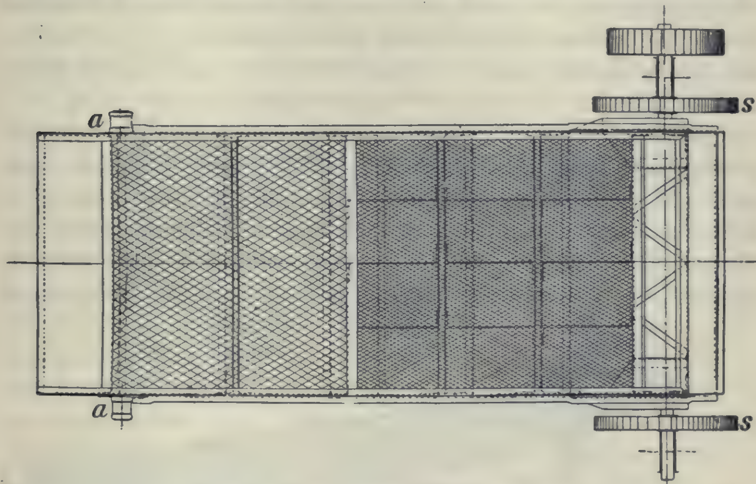


Fig. 60. Top View of Shaking Screen

the screen perforations in plate "c" into the spout "d" and onto the second screen. Coal bigger than 1¼ in. passes to the

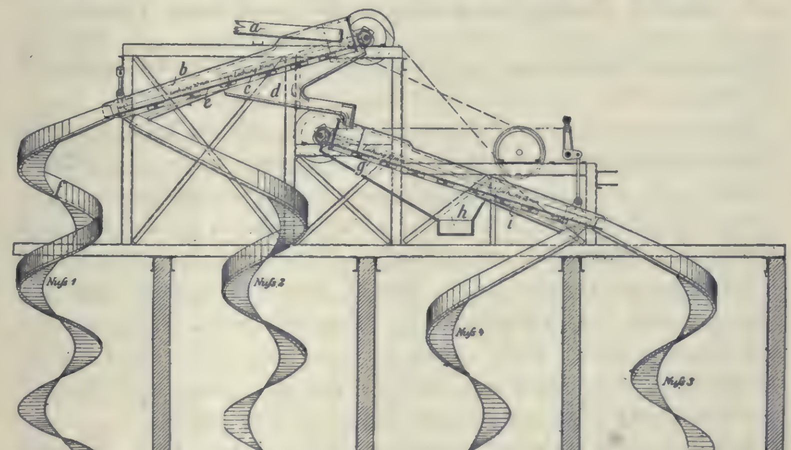


Fig. 61. Shaking Screen Installation on Top of Washed Coal Bins

screen plate "e" of the first screen. The oversize from 2 in. to 3 in. drops into the spiral chute "f" and passes into bin No. 1.

The undersize from 1¼ in. to 2 in. goes to bin No. 2. On the first screen plate of the second screen, having ⅜ in. perforations, the fine coal and the wash water are separated from the balance of the material and carried away in the sluice "h." The undersize of the screen plate "i" from ⅜ to ¾ in. goes to bin No. 4, and the oversize from ¾ to 1¼ in. is deposited in bin No. 3.

Shaking screens with superimposed screen plates are used for preliminary sizing as shown in Fig. 62. The whole screen rests upon two crankshafts "c" and "d" that are connected by a belt drive "e." The uniform motion of the whole screen lifts the coal at each stroke off from the screen plates and throws it forward. The subsequent drop of the coal onto the screen tends

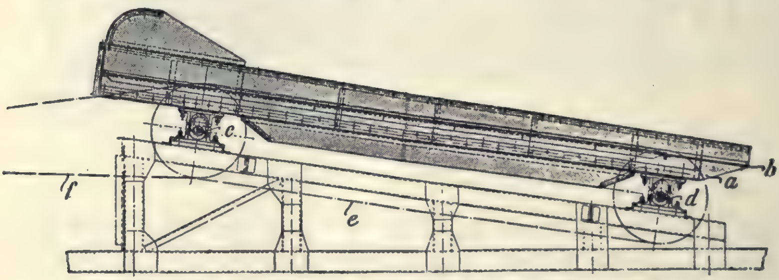


Fig. 62. Shaking Screen with Superimposed Screen Plates

toward exact sizing and the forward motion of the coal makes it possible to place the screen at a very slight slope.

Shaking screens are either supported on rollers, hung by rods from above or supported from above or below by means of planks (either oak or ash) rigidly attached to the screen frame. The form of shaking screen with the plank supports placed below is called the "Parrish" screen and not only are its supports of wood fastened tightly to the frame, but its eccentric rods are also of wood, firmly fastened to the screen body. This wooden construction makes the Parrish screen light, while the rigid attachment of the planks and rods results in a sharp upward jerk on each stroke of the screen, which is highly effective.

The following data on screens are taken from "Coal Washing in Illinois," by F. C. Lincoln, Bulletin No. 69 of the Engineering Experiment Station of the University of Illinois.

The two shaking screens treating raw coal make 132 strokes

per minute and screen 52 per cent. of ¾ in. coal out of 3½ in. screenings at the rate of one ton per hour for each 0.7 sq. ft. of screening surface.

Twelve revolving screens are used for sizing the raw coal prior to washing. Nine of them are cylindrical and three conical. One is a simple cylindrical screen and one a simple conical screen. Two are single jacketed cylindrical screens making two sizes, one is a double jacketed cylindrical, four are triple jacketed cylindrical, while the remaining three are triple jacketed conical revolving screens. The cylindrical screens are placed at a slope ranging from 3 to 7 deg., with an average of 5 deg. The conical screens have all their axes in a horizontal position. The number of revolutions per minute varies from seven to 30, giving peripheral speeds ranging from 126 to 471, with an average of 219 ft. per minute. The square feet of screen surface per ton treated per hour varies from 1 to 11.3, with an average of 4.2. F. E. Brackett[1] holds that this ratio should be 8 when the mesh is ¾ in. and 16 when it is ¼ in., indicating that the raw screens in Illinois are not as large as elsewhere in the United States.

For the final screening of the washed coal shaking as well as revolving screens are used in Illinois. The shaking screens employed for re-sizing of the washed coal have an average slope of 10½ deg., make 155 strokes—of 4½ in. length—per minute, and have 1.35 sq. ft. of screen surface per ton of coal per hour.

The shaking screens employed for sizing coal not previously sized while raw give the following averages: Slope, 9 deg., strokes, 135 (of 5 in. length) per minute, square feet of screening surface per ton per hour, 1.7. We have seen that 0.7 sq. ft. per ton of raw coal per hour is the average bituminous practice. Wet coal requires more screening surface and the Illinois shaking screens conform to this requirement by having twice that area. The revolving screens used for sizing of the washed coal have an average peripheral speed of above 200 and below 250 ft. per minute. The average square feet of screen area per ton per hour for raw coal revolving screens was found to be 4.2. Wet revolving screens should have larger proportional areas and the average of 5.66 and 6.5 sq. ft. for resizing and final sizing screens,

[1] *Coal Age*, Vol. 3 (1913), page 131.

respectively, appear at their face to show that this requirement is carried out.

The following table shows the percentage of the different sizes produced in Illinois washeries:

	No. 1 Per Cent.	No. 2 Per Cent.	No. 3 Per Cent.	No. 4 Per Cent.	No. 5 Per Cent.
Average for 8 washeries making five sizes (Central Field)	11.85	17.92	18.47	26.72	25.04
Average for 4 washeries making five sizes (Southern Field)	20.99	21.42	13.25	26.62	11.72

The sizes to which these proportions refer are indicated in the following table:

	No. 1	No. 2	No. 3	No. 4	No. 5
Central Field					
5	3–1¾	1¾–1¼	1¼–¾	¾–5/16	5/16–1/16
5	3½–1¾ sq	¾ sq–1 sq & 1⅜	1 sq & 1⅜–⅞	⅞–¼	¼–0
5	3½–2¼	2¼–1¼	1¼–⅞	⅞–⅜	⅜–0
5	3–1⅞	1⅞–1¼	1¼–⅞	⅞–5/16 & ¼	5/16 & ¼–0
5	3–1¾	1¾–1⅛	1⅛–¾	¾–¼	¼–0
5	3–1¾	1¾–1	1–¾ & ½	¾ & ½–¼	¼–0
5	3–1¾	1¾–1⅛	1⅛–¾	¾–¼	¼–1/16
5	2 & 1¼–1½	1½–1	1–⅜	⅜–¼	¼–3/16
5	3–1¾	1¾–1⅛	1⅛–¾	¾–⅜	⅜–1/16
5	3–1¾	1¾–1¼	1¼–¾	¾–⅜	⅜–0
5	3–1¾	1¾–1	1–¾	¾–¼	¼–0
5	3–2	2–1⅛	1⅛–11/16	11/16–¼	¼–1/16
Southern Field					
5	3–2	2–1	1–¾	¾–¼	¼–0
5	3–1¾	1¾–1¼	1¼–¾	¾–7/16 & ⅜	7/16 & ⅜–0
5	3½–1¾	1¾–1	1–¾	¾–5/16&¼&½ sq	5/16&¼&½ sq–0
5	3–2	2–1	1–¾	¾–¼	¼–0

CHAPTER XIV

THE REMOVAL OF TRAMP IRON

In the mining of coal foreign substances are mixed with the coal and carried with it through the washery. It is difficult to avoid this. Especially harmful are pieces of iron. They cause trouble and wrecks in the crushing plants, and work havoc with the conveyors and feeders. Furthermore, on account of their

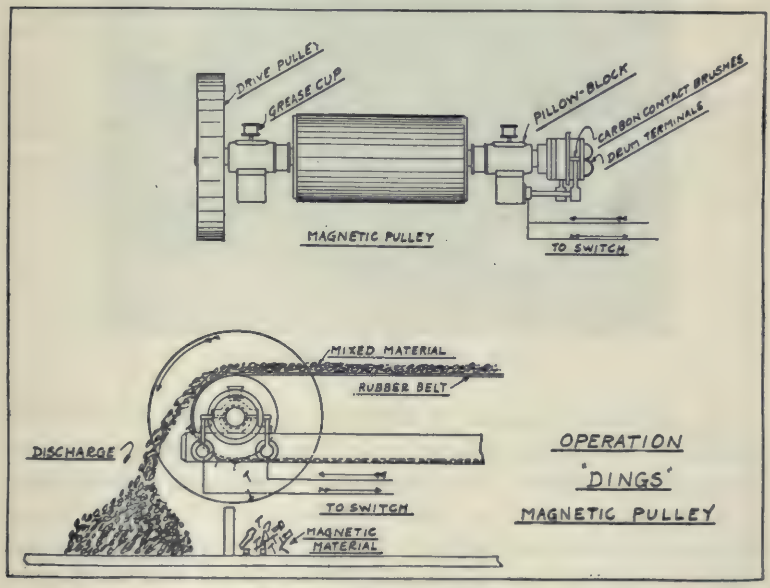


Fig. 63. Magnetic Pulley

heavy weight they remain on the jig screens, where they form a heavy bed that prevents the required loosening up of the materials by weakening the water pulsation. This is detrimental to the effective operation of the jigs.

If a mine sends out a good deal of tramp iron, it is advisable to install a separate apparatus to catch all this foreign material.

On account of the strong magnetic properties of iron a magnetic separator is the logical selection. Magnetic separators are simple and offer no difficulties. Any well-designed magnetic separator is adapted for this purpose, only it must be designed to handle great quantities. Magnetic separators are mainly of the revolving type and are either located in the bottom of a chute or in the head pulley of a belt conveyor. Revolving magnets have the advantage that they deliver the attracted iron automatically into a separate chute. Sometimes flat magnets are hung above the chutes, but in this case the attracted iron must be removed by hand.

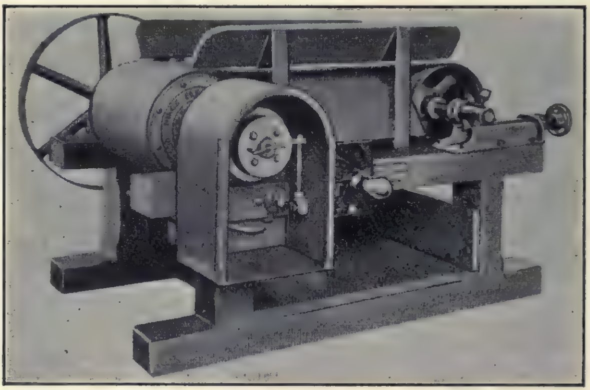


Fig. 64. Magnetic Separator

The operating principle of these machines is very simple. The material to be separated is fed upon a belt conveyor passing over a magnetized pulley. The non-magnetic material falls by gravity from the brow of the pulley vertically into a suitable receptacle or to a conveyor leading to final delivery, while the iron and magnetic material are attracted and held firmly against the belt until it is carried to the point where the belt leaves the pulley on the under side and is there discharged back of a partition set a few inches beneath the pulley in line with its axis.

If, however, the coal is handled by an elevator, a magnetic separator can easily be installed between the elevator head and the discharge chute. Such an apparatus is shown in Fig. 64.

The vital and expensive part of such a separator is the pulley

magnet and its present design is the development of years of experience in building this class of machinery. The face of a magnet is made "crowning" which keeps the conveyor running

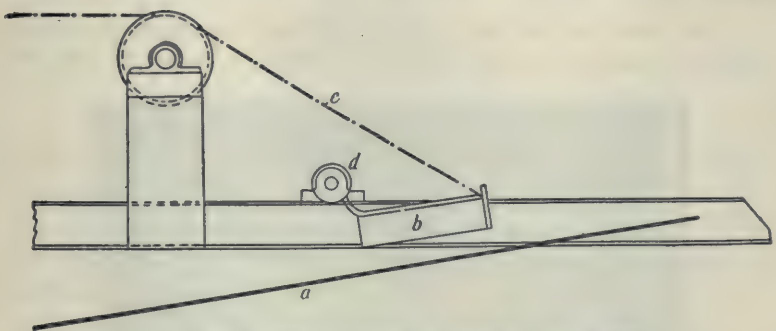


Fig. 65. Magnets Installed Over Shaking Screen

central without guides or other troublesome devices. Heavy bronze non-magnetic end plates prevent iron and steel particles from attaching themselves and clinging to the ends of the pulley. The magnet is built upon a hollow shaft which provides means

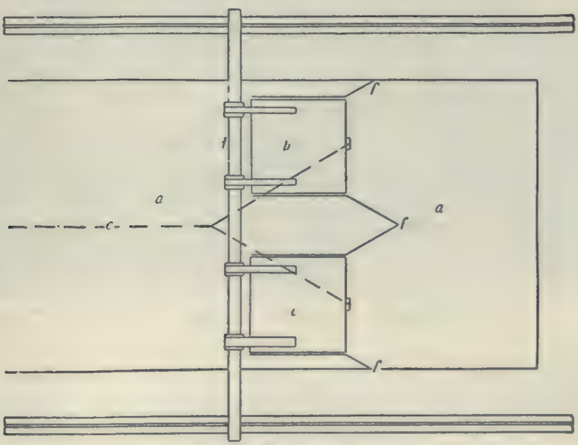


Fig. 66. Top View

for conducting the wires connecting the energizing coils with the contact parts. The contact parts are placed outside of one of the bearings. This permits of a substantial housing convenient

and easily opened for inspection. The separator is equipped with driving pulley, take-up boxes, slate switch panel, pilot lamp, kick-absorbing switch, steel housing for contact parts, bilge boards, etc.

If the raw coal is sized before washing, the magnets can be readily installed over the screens as shown in Figs. 65 and 66.

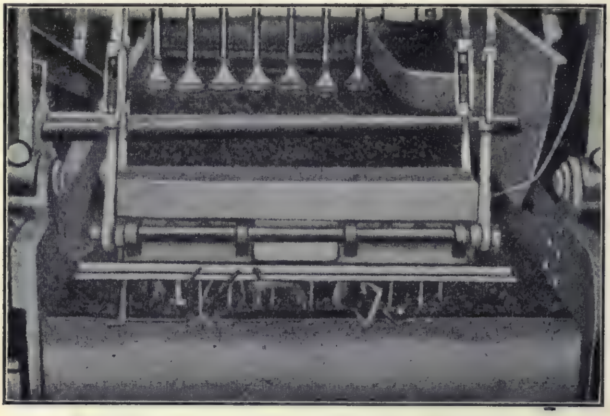


Fig. 67. Magnets Hung Over Shaking Screen

The magnets "b" are hung from a shaft "d" from about 4 to 6 in. above the screen plates and kept in place by a rope "e." The coal is forced by the guide plates "f" to pass under the magnets. At certain intervals the magnets are lifted and the adhering tramp iron removed. Fig. 67 shows a photograph of such an installation.

CHAPTER XV

WEIGHING AND SAMPLING APPARATUS

For a proper control of the process it is advisable to install continuous automatic weighing apparatus for the raw coal and for the washed product. If belt conveyors are used to convey the coal the installation of such apparatus is simple. Fig. 68 shows the "Merrick conveying weigher" installed in a belt con-

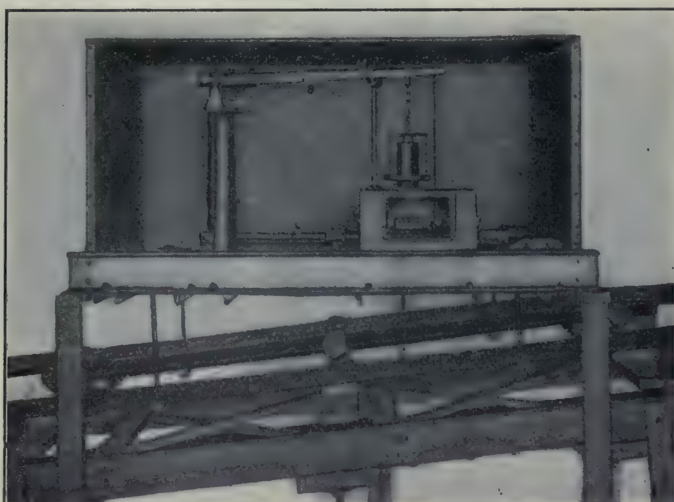


Fig. 68. Merrick Conveyor Weightometer

veyor, with front sheet of casing removed. Fig. 69 shows the installation under working conditions. The integrator and counter can be seen through the window.

The Merrick conveyor weightometer solves in an economical manner the problem of weighing bulk material while it is carried on a belt conveyor and of making a record of the weight of the passing load without stopping its flow.

Several of the troughing idlers which support the conveyor

belt are placed upon suspension angles which hang from suspension rods. These rods, by knife-edged pivots, are connected with a system of levers, which, in turn are connected with the weighing beam. This beam is automatically brought to poise for different loads on the conveyor by a steel cylinder hanging from the beam and floating in mercury. As the loads vary the cylinder floats at different levels on the mercury, permitting the beam to tilt in proportion to the weight.

A slender rod attached to the end of the weighing beam above connects it with the weight-indicating mechanism. A frame sup-

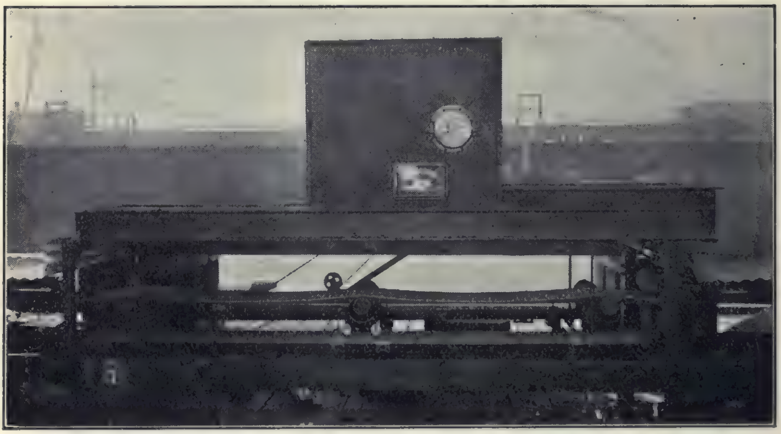


Fig. 69. Merrick Conveyor Weightometer

ports this mechanism, and is so pivoted that the changes in the position of the weighing beam are communicated to it by the connecting rod just mentioned, so as to tilt it to a degree which depends on the deflections of the weighing beam.

Mounted across the bars of the tiltable frame is the shaft of the weight-indicating disc. While free to revolve between the bars, the disc is forced to tilt with the frame to which it is attached. In accordance with the weight on the conveyor this disc is tilted from the vertical to a varying degree.

Into the edge of the disc, all around the periphery, small rollers are set, which come in contact with a narrow endless belt at two diametrically opposite points of the disc's periphery. This belt is driven in a horizontal circuit by a pulley deriving

its power from the conveyor belt. When no load is on the conveyor and the disc correspondingly stands vertically, the narrow belt runs at right angles to the plane of the disc. As soon as the disc is tilted by the conveyor load, its position relative to the driving belt, with which it is in contact, will change. Even a slight tilt will cause the belt to give to the disc a slow rotary motion and the greater the tilt, the nearer the plane of the disc coincides with the plane of the belt circuit, the greater will be the speed of the disc. A five-figure counter operated by the end of the disc-shaft records the rotations of the disc. By correctly choosing the speed reduction between the conveyor and the narrow driving belt of the weighing mechanism, the counter will indicate weight in pounds, tons, kilos, or any other units.

This device, once installed and properly adjusted, does its work faithfully and correctly and requires but little attention.

The installation of a continuous weighing apparatus is important for the proper control of a coal washery. The raw coal, the washed coal and even the refuse should be weighed. At present the mine weight is accepted for the raw coal. If the coal is taken directly from the mine to the washery this method might be excused, but since in most cases a storage bin is placed between the mine and the washery, it is impossible to determine the exact amount of raw coal entering this plant. The weight of the washed coal is mostly determined by weighing the outgoing railroad cars or if the washed coal is taken in larries to the coke ovens, by the number of larries. These are, of course, supposed to be uniformly loaded. This, however, does not always give the exact amount of washed coal produced, since some of the coal remains in the bins.

Refuse is hardly ever weighed. The number of refuse cars are marked on a tally board and an arbitrary weight taken for the contents of each car. By installing continuous automatic weighing machines for the raw coal, the washed coal and the refuse a close control can be established over the washing process and guess work and haphazard methods eliminated. The Merrick weightometer is guaranteed to give 99 per cent. accuracy and to maintain without trouble continuous 24-hr. service.

Automatic Sampling Apparatus. Besides the utility of knowing the correct weight of all materials entering and leaving a

washery it is of equal if not greater importance to collect a correct average sample of the products. At present sampling is mostly done by boys, who take samples of the raw coal, the washed coal, the refuse and the sludge at regular intervals. In ore-dressing plants the sample boy has long ago been replaced by automatic sampling machines and it is high time that similar methods should be introduced into coal washeries. In the general lay-out of a coal washery provision ought to be made to permit the installation of sampling machines. For the sampling of raw or washed coal and the refuse a sampling machine similar to the one shown in Fig. 70 may be employed.

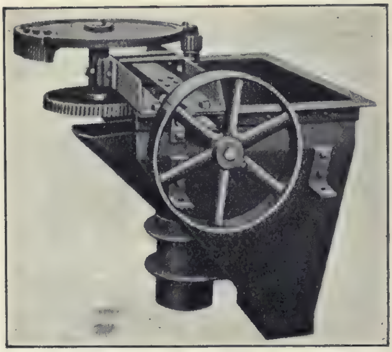


Fig. 70. Intermittent Sampling Machine (Built by Colorado Iron Works Co.)

This machine is a modification of the "Vezin" sampler and takes a comparatively small sample at long intervals. It can be geared so that a sample is taken every 15, 20 or 30 min. during the day. The samples are collected in a receptacle which can be locked and sealed. This machine can be installed at the head of an elevator or conveyor and the sample taken across and through the stream of coal. For the sampling of sludge and dirty water a tailing sampler operated by a stream of water can be used. This apparatus is shown in Fig. 71.

The tailings sampler here shown is placed at any convenient point and causes practically no loss. It is operated by a stream of water, the flow of which regulates the frequency with which a sample is taken. The tank at the top of the machine is divided into two compartments, one on each side of the point of suspen-

sion, which serve for the operation of the machine. The stream of water enters one compartment until the equilibrium is overcome, when it causes the splitter to sweep slowly across the end of the launder and take an even sample clear across, depositing it in a suitably placed box or pan.

The side of the tank which is weighted has now become the low side and the water escapes gradually through a small hole while the opposite side is filling. By varying the flow of water

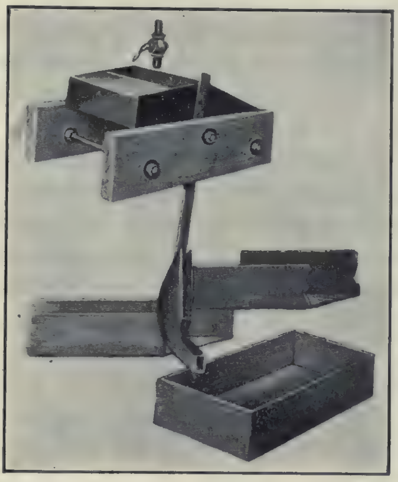


Fig. 71. Sampling Machine for Tailings

the frequency of sampling can be varied within wide limits, 20 gals. per hour sufficing to operate it when taking samples at five-minute intervals.

The cutter of a sampler must pass through the stream of coal in such a way as to take an equal proportion of all parts of it. The only safe way of passing the sample cutter through the stream of coal is with its edge in a plane at right angles to the long axis of the stream, the cutter entering at one portion and passing with uniform motion entirely through and out at the opposite portion. It will be safer to pass the cutter through the stream from side to side, discharging from a spout than from front to rear or rear to front, for in the latter cases unless the cutter is introduced into the stream at some distance below the

point of discharge the reaction of the large grains striking the edge of the cutter will tend respectively to throw them into the cutter or away from it, whereas for accurate sampling there should be no marked tendency in this respect one way or the other. When wet coal is being sampled, the interior of the cutting device should be cleaned at proper intervals for the wet coal tends to cling to the sides in the rear portion where the fine coal falls in a side to side cut, eventually leaving only a confined space and reducing the proportion of fines. The unvarying frame of mind of those having charge of sampling should be one of suspicion. Due care should be exercised that all sampling apparatus is kept clean and running freely. It is an excellent plan to mount a revolution counter upon the samples, or on gearing driving them to record revolutions during one shift.

It is of equal importance that provisions for the installation of automatic samplers should be made in the arrangement of the machinery. Automatic samplers ought to be part of the installation just as much as jigs, elevators, conveyors, etc.

CHAPTER XVI

PREPARATORY INVESTIGATIONS

The more or less successful selection or construction of a jig determines the economic success of a washery. The commercial results of a washery are influenced by the efficient yield of the jigging process. The yield of a washery is the proportion of the washed coal to the raw coal, or of the output to the input. A washery which produces 1200 tons of washed coal from 1500 tons of raw coal has a yield of $1200 \div 1500 \times 100 = 80$ per cent. This yield depends upon the ash content of the washed coal.

It is impossible to make an absolutely perfect separation of coal from refuse. Some refuse will be carried over with the washed product and a certain percentage of good coal goes into the refuse. This imperfection of jigging brings about a decrease in the yield which is in direct proportion to the reduction of ash. The possible yield with a predetermined amount of ash is influenced by the composition of the raw coal and can only be determined in each special case by a thorough investigation. If the possible limits have been determined consideration must be given to the selling price of washed coals having different percentages of ash. The yield, percentage of ash and the selling price must be considered together in order to arrive at the maximum total value of the washed coal.

A typical example will illustrate this. Let us assume that the possibility of putting a coal on the market commences at 8 per cent. of ash. The assumed price of coal with this ash content is taken at \$3 per ton, and for each 1 per cent. decrease in ash the selling price advances 25c. per ton. Experiments gave the following results: An 8 per cent. ash gave 95 per cent. yield; a 6 per cent. a 90 per cent. yield, and a 4 per cent. ash gave an 85 per cent. yield. The price for the different coals will therefore be as follows:

$$8 \text{ per cent. ash coal} = \frac{95 \times 3.00}{100} = \$2.85$$

$$6 \text{ per cent. ash coal} = \frac{90 \times 3.25}{100} = \$2.925$$

$$4 \text{ per cent. ash coal} = \frac{85 \times 3.50}{100} = \$2.80$$

This shows that the best returns would be received by washing the coal down to 6 per cent. ash.

The results secured from the tests for the yield and percentage of ash can be used to calculate the composition of the different products if the amount and percentage of ash in the raw coal are known. If 3,000 tons of raw coal with 10 per cent. ash are to be washed, we get the following results:

	Composition of Washed Product			Composition of Refuse		
	Combustible, Tons	Ash, Tons	Total Tons	Combustible, Tons	Ash, Tons	Total Tons
With 8 per cent. ash, 95 per cent. yield	2,622	228	2,850	78	72	150
With 6 per cent. ash, 90 per cent. yield	2,538	162	2,700	162	138	300
With 4 per cent. ash, 85 per cent. yield	2,448	102	2,550	252	198	450

The figures given in the table, even if exact conditions are not known, permit us to draw a conclusion in regard to the composition and nature of the raw coal. The raw coal is comparatively clean, containing only 10 per cent. ash. The impurities are mostly bone coal. This can be judged by the large percentage of good coal in the refuse, which can only be caused by a slight difference in the specific gravity between the coal and refuse.

The foregoing example is carried out for unsized coal. If sized coal is to be studied, determinations for each size must be made separately. In actual practice many other factors must be considered which, however, cannot be expressed in such a simple way by means of figures. The most important of such considerations are:

(1) The possibility of using the refuse as boiler fuel or of re-

covering some good coal from it, by crushing and rewashing. The refuse shown in the example given could be easily used at the mine for boiler fuel. (2) As the cost of washing becomes greater with crushing and rewashing, this cost must be deducted from the price derived from the sale of the recovered refuse. (3) The possibility of making through close washing an especially clean and valuable coal that will be in demand even under adverse circumstances, may change the conditions mentioned considerably. This advantage can not be expressed in figures and should be especially considered by those mines that on account of the poor quality of their raw coal can not compete in the market with producers better situated.

The economic operation of a washery can only be based upon a complete and intelligently conducted washing test. The first step in such an investigation is to make a chemical survey of the mine. This consists in making careful sections of the coal bed in different portions of the mine, taking samples of the coal and impurities in the proportion in which they exist in the vein (so-called channel samples). These samples are taken down to the size to which the coal will be crushed at the washery. The samples are then mixed in equal proportion by weight, all fine material which passes through a 20-mesh screen is screened out for separate treatment, and the main sample is separated or classified by means of heavy solutions of varying specific gravity.

The objects sought by such procedure are, first, to obtain the theoretical ash or fixed ash in the pure coal, and second, to so classify the impurities as to plainly show the quantities, specific gravity and ash content of each class. For example, a coal which presents rather difficult washing problems shows the following results for the so-called sink-and-float test:

Pure coal lighter than	1.35 sp. gr.,	69.7 per cent. with	7.11 per cent. ash
Impurities	1.35–1.40 sp. gr.,	8.3 per cent. with	14.67 per cent. ash
Impurities	1.40–1.45 sp. gr.,	3.6 per cent. with	19.10 per cent. ash
Impurities	1.45–1.50 sp. gr.,	2.2 per cent. with	24.20 per cent. ash
Impurities	1.50–1.55 sp. gr.,	1.0 per cent. with	28.02 per cent. ash
Impurities	1.55–1.75 sp. gr.,	2.2 per cent. with	34.65 per cent. ash
Impurities	1.75 and over,	13.0 per cent. with	73.00 per cent. ash
Total raw coal		**100.0 per cent. with**	**18.08 per cent. ash**

From the foregoing it can be calculated that the ash in the washed coal would be 8.71 per cent. if the separation is made at

1.45 specific gravity and 9.10 per cent. if made at 1.55 specific gravity, assuming, of course, perfect washing. In the former case the washery loss would be 18.48 per cent. and in the latter 15.2 per cent., assuming that the refuse is free from coal.

A chemical survey of a mine, if properly conducted, will give accurate information on the following points: The amount and character of impurities in the run-of-mine coal; the amount of fixed ash or that in the pure coal; the amount of rejection which it will be necessary to make with a coal washer to produce any desired quality of washed product; the amount and character of impurities, if any, that could be drawn off as an intermediate product and used for boiler fuel, together with the heat value of such intermediate product; the composition of the washed product that may be expected; the size best adapted for the separation of the impurities; the units of machinery best adapted to produce the desired results with the least construction cost. In other words, such an investigation will show the financial returns that may be expected from a washery.

The following table gives the results of a float and sink determination made under actual operating conditions of a pan jig washery treating Alabama coal of the "Big Seam Bed":

ANALYSES OF RAW COAL, WASHED COAL AND REFUSE

Raw Coal		Ash per cent.	Sulphur per cent.
General Sample		17.40	0.67
Above ¾ in.	47.5 per cent.	27.13	
Lighter than 1.35 sp. gr.	64.9 per cent.	9.72	
Lighter than 1.45 sp. gr.	5.4 per cent.	21.38	
Heavier than 1.45 sp. gr.	29.7 per cent.		
	100.0 per cent.		
Through ¾ in.	52.5 per cent.	11.70	
Lighter than 1.35 sp. gr.	85.3 per cent.	8.41	
Lighter than 1.45 sp. gr.	5.7 per cent.	20.80	
Heavier than 1.45 sp. gr.	9.0 per cent.		
	100.0 per cent.		
Washed Coal			
General Sample		9.30	
Above ¾ in.	21.2 per cent.	10.16	
Lighter than 1.35 sp. gr.	90.1 per cent.	9.67	
Lighter than 1.45 sp. gr.	6.4 per cent.	19.79	
Heavier than 1.45 sp. gr.	3.5 per cent.	36.24	
	100.0 per cent.		

Through ¾ in.	78.8 per cent.	8.90
Lighter than 1.35 sp. gr.	93.8 per cent.	7.60
Lighter than 1.45 sp. gr.	3.6 per cent.	22.71
Heavier than 1.45 sp. gr.	2.6 per cent.	38.45
	100.0 per cent.	

Refuse

General Sample		63.84
Above ¾ in.	65.1 per cent.	71.85
Through ¾ in.	34.9 per cent.	60.73
Lighter than 1.35 sp. gr.	15.2 per cent.	11.85
Lighter than 1.45 sp. gr.	1.0 per cent.	25.65
Heavier than 1.45 sp. gr.	83.8 per cent.	71.72
	100.0 per cent.	

TABLE 18

The tables on pages 138–39 from T. J. Drakeley's scientific study of coal washing give interesting data of the work done by different types of coal washeries in England.

The following extract from a report made by David Hancock—preliminary to the installation of a washery—will shed some light upon the mooted question of the removal of sulphur. It shows clearly that the bottom-bench coal could not be improved by washing.

The coal of the Nickle Plate bed occurs in two benches entirely different in their characteristics. The bed has the following average section:

18½ in. of top coal, specific gravity	1.27
1 in. of slate parting.	
14½ in. of bottom coal, specific gravity	1.48
34 in. total thickness of bed.	

The top coal was sampled separately in each case, then a sample was taken of the bottom coal, including the parting, the sections were carefully cut to uniform width and depth from top to bottom. This gave eight good samples, weighing about 10 pounds each. In the laboratory, the samples were put through a screen having ⅞ in. round perforations and thoroughly mixed.

An equal weight of each sample was then taken, the four samples of top coal being mixed to form an average sample of the top bench, and the four samples of the bottom coal similarly weighed and mixed to form an average sample of the bottom bench. These two samples were then sized into three sizes, i. e.,

Results of Tests on Samples from a Luhrig Coal-Washer

Particulars	Coal free from visible impurity	Raw coal	Washed coal: Inches—0–5/16	Washed coal: Inches—5/16–11/16	Washed coal: Inches—11/16–1 3/8	Washed coal: Inches—1 3/8–2 1/2	Refuse (Percentage)
Ash percentage	2.61	11.63	6.12	3.91	(3.60)	3.93	66.71
Sulphur percentage	0.39	0.50	0.47	0.42	—	0.41	0.89
Chlorine percentage	0.01	0.01	0.01	0.01	—	0.01	0.01
Calorific value	8,002	7,241	7,577	7,849	—	7,841	—
Caking power	17	15	16	16 +	—	16 +	—
Ash-fusion temperature, in degrees Centigrade	—	1,380	1,370	1,370	—	1,380	—
Float percentage	—	86.33 —	93.63 —	97.51 —	— —	97.43 —	8.31 —
Sink percentage	—	— 13.67	— 6.37	— 2.49	— —	— 2.57	— 91.69
Ash percentage	—	2.84 66.80	2.87 53.86	2.73 51.31	— —	2.74 51.77	7.92 72.21

General efficiency of the washing process = 69.77 per cent.

Results of Tests on Samples from a Coppee Coal-Washer

Particulars	Coal free from visible impurity	Raw coal	Washed coal: Inches—0–3/8	Washed coal: Inches—3/8–3/4	Washed coal: Inches—3/4–1 1/2	Refuse (Percentage)
Ash percentage	4.35	17.37	10.90	8.97	8.58	60.13
Sulphur percentage	1.38	3.26	1.85	1.73	1.66	6.07
Chlorine percentage	0.13	0.18	0.14	0.13	0.13	0.22
Calorific value	7,713	6,497	7,186	7,352	7,387	—
Caking power	16	15	16 —	16	16	—
Float percentage	—	78.22 —	89.89 —	93.86 —	95.19 —	11.62 —
Sink percentage	—	— 21.18	— 10.11	— 6.14	— 4.81	— 88.38
Ash percentage	—	5.61 61.44	5.24 61.93	5.56 61.13	5.98 60.11	8.18 66.96

General efficiency of the washing process = 64.63 per cent.

RESULTS OF TESTS ON SAMPLES FROM A ROBINSON COAL-WASHER

Particulars	Coal free from visible impurity	Raw coal		Washed coal Inches—0–½		Refuse (Percentage)	
Ash percentage	2.63	9.13		4.73		55.03	
Sulphur percentage	0.41	0.47		0.42		0.78	
Calorific value	7,992 C.H.U.	7,362		7,801		—	
Caking power	17	16 +		17 —		—	
Ash-fusion temperature, in degrees Centigrade	—	1,380		1,370		—	
Float percentage	—	88.46	—	96.12	—	14.55	—
Sink percentage	—	—	11.54	—	3.88	—	85.45
Ash percentage	—	2.88	56.89	2.78	53.20	8.21	62.80

General efficiency of the washing process = 65.18 per cent.

RESULTS OF TESTS ON SAMPLES FROM A BAUM COAL-WASHER

Particulars	Coal free from visible impurity	Raw coal		Washed coal Inches—0–⅜		Washed coal Inches—⅜–1		Washed coal Inches—1–2		Refuse (Percentage)	
Ash percentage	3.47	19.62		10.76		8.03		7.87		70.36	
Sulphur percentage	1.08	1.82		1.33		1.16		1.13		6.09	
Soluble sulphur percentage	0.06	0.09		0.07		0.05		0.05		0.42	
Calorific value	7,741 C.H.U.	6,358		7,172		7,359		7,384		—	
Caking power	14	13		13		14		14		—	
Float percentage	—	77.38	—	91.54	—	95.60	—	95.87	—	9.10	—
Sink percentage	—	—	22.62	—	8.46	—	4.40	—	4.1	—	90 90
Ash percentage	—	5.35	68.42	5.28	67.84	5.41	65.02	5.53	62.29	8.16	77.13

General efficiency of the washing process = 72.38 per cent.

⅞ in. to ⅜ in., ⅜ in. to 20 mesh, and through 20 mesh. Separations at 1.35 sp. gr. were made on each size. The following results were obtained from these separations:

Top Bench

Size	Amount Per cent.	Separation at 1.35 sp. gr.		Analysis of Float	
		Float Per cent.	Sink Per cent.	Ash Per cent.	Sulphur Per cent.
⅞ in.–⅜ in.	30	95.2	4.8	2.35	0.87
⅜ in.–20 mesh	60	95.6	4.4	2.21	0.88
Through 20 mesh	10	86.0	14.0	2.75	0.88
Average	100	94.5	5.5	2.35	0.88

Table 19

Bottom Bench

Size	Amount Per cent.	Separation at 1.35 sp. gr.		Analysis of Float	
		Float Per cent.	Sink Per cent.	Ash Per cent.	Sulphur Per cent.
⅞ in.–⅜ in.	34.2	31.2	68.8	8.25	3.03
⅜ in.–20 mesh	57.4	44.6	55.6	7.50	2.85
Through 20 mesh	8.3	62.5	37.5	8.85	3.20
Average	100.0	41.4	58.6	7.88	2.95

Table 20

The average of the entire bed was then calculated, taking into consideration the thickness and specific gravity and all of the sink in 1.35 sp. gr. mixed in the proper proportions to represent the sink from the entire bed and further classified as follows:

Combined Float, Entire Vein including Parting and Classification of Sink

Class	Amount Per cent.	Ash Per cent.	Sulphur Per cent.
Coal lighter than 1.35 sp. gr.	72.3	4.20	1.57
Impurities 1.35–1.40 sp. gr.	6.4	12.65	4.70
Impurities 1.40–1.45 sp. gr.	4.8	16.40	5.43
Impurities 1.45–1.50 sp. gr.	4.0	18.90	6.67
Impurities 1.50–1.55 sp. gr.	2.0	23.20	6.85
Impurities 1.55–1.75 sp. gr.	4.4	32.78	5.39
Impurities 1.75 and over sp. gr.	6.1	65.23	5.14

Table 21

To assist in forming an idea of this proposition, I have calculated from the foregoing results the following figures, showing

what the results would be if perfect separation was secured (1) at 1.35 sp. gr., (2) at 1.45 sp. gr., and (3) at 1.55 sp. gr., and finally the average raw coal for the entire bed:

	Amount of Coal Per cent.	Amount of Refuse Per cent.	Analysis of Coal Ash Per cent.	Analysis of Coal Sulphur Per cent.
Separation at 1.35 sp. gr.....	72.3	27.7	4.20	1.57
Separation at 1.45 sp. gr.....	83.5	16.5	5.54	2.04
Separation at 1.55 sp. gr.....	89.5	10.5	6.31	2.35

TABLE 22

Average Raw Coal Analysis. Ash: 11.07 per cent.; Sulphur: 2.65 per cent. It will be noted that when the coal is crushed to ⅞ in. size, a perfect separation at 1.55 sp. gr., which is better than could be expected of any washer, would result in a rejection of practically 10 per cent. of the product, a reduction of ash from 11.07 per cent. to 6.31 per cent., and a reduction of sulphur from 2.65 per cent. to 2.35 per cent.

The important point brought out is that the sulphur, while apparently in the form of FeS_2 is in a finely pulverized condition and intimately mixed with the coal. The float in 1.35 sp. gr. from the bottom bench carrying 3 per cent. of this substance does not show any sulphur visible to the eye.

When the proposition of finer crushing is considered, it becomes important to know the composition of the material finer than 20 mesh and what can be done with it. Therefore I have determined the composition of material through 20 mesh in these samples, as follows:

SEPARATION AT 1.35 SP. GR. OF MATERIAL THROUGH 20 MESH

	Amount of Float Per cent.	Amount of Sink Per cent.	Analysis of Float Ash Per cent.	Analysis of Float Sulphur Per cent.	Analysis of Sink Ash Per cent.	Analysis of Sink Sulphur Per cent.
Top bench	86.0	14.0	2.75	0.88	33.88	7.65
Bottom bench	62.5	37.5	8.85	3.20	42.50	5.78

TABLE 23

It should be noted here that when the bottom bench coal is crushed to 20 mesh size and separated by a 1.35 sp. gr. solution, the float still contains 3.20 per cent. of sulphur.

This shows conclusively that this coal could not be brought to a coking standard by washing. Similar coals are found elsewhere in the United States, especially in the southern part of Illinois.

Reinhardt Thiessen, research chemist of the U. S. Bureau of Mines, proved conclusively in a paper presented before the American Institute of Mining and Metallurgical Engineers, that pyrite besides occurring in the coal in form of balls, lenses, nodules, continuous layers and thin sheets, or flakes, occurs also as fine microscopic particles, or nodules, disseminated through the compact coal. Finally there is sulphur in coal in an amicroscopic form (not visible with an ordinary microscope), probably combined with the organic matter that exists in the coal. The microscopic particles of pyrite vary in diameter from a few microns to a hundred microns, the majority measuring from 25 to 40 microns. (A micron is a unit of length equal to 0.001 millimeter, or about 0.00004 inch.) Thiessen further states that a certain amount of sulphur has been found to be present in coal in an amicroscopic form. Although, in certain samples, no sulphur can be detected ordinarily by the microscope, microchemical and qualitative chemical tests reveal sulphur. Recent observations and analyses of a large number of samples from different coals have shown that, in a number of cases more sulphur is found than can be accounted for, if this material were combined only with the minerals found in coal. This form of this element is probably that recognized as organic sulphur. Little or nothing is known about it except that sulphur exists in this form. There are, however, a number of observations on record that lead one to assume that it is present as such. The above investigation of the bottom bench of the Nickle Plate bed tends to strengthen this belief and the following analyses of coal from the No. 6 Illinois bed shows that either amicroscopic pyrite or organic sulphur exists in this coal.

Analysis of Franklin County (Illinois) Coal

Ash	11.48 per cent.
Sulphur	2.15 per cent.
Volatile matter	37.85 per cent.
Fixed carbon	50.67 per cent.

Screening Tests

	On screen Per cent.	Ash Per cent.	Sulphur Per cent.
Held on 1 in. screen..	14.30	13.53	1.58
Passing 1 in........Held on ¾ in. screen..	11.48	12.30	1.89
Passing ¾ in........Held on ½ in. screen..	21.26	12.78	2.02
Passing ½ in........Held on ¼ in. screen..	18.26	11.59	2.03
Passing ¼ in........Held on ⅛ in. srreen..	15.44	9.78	1.92
Passing ⅛ in........Held on 10 mesh....	2.48	9.43	1.88
Passing 10 mesh....Held on 20 mesh....	6.30	11.12	1.87
Passing 20 mesh....Held on 30 mesh....	3.19	13.04	2.09
Passing 30 mesh....Held on 40 mesh....	1.56	14.63	2.19
Passing 40 mesh....Held on 50 mesh....	1.00	12.85	2.21
Passing 50 mesh....Held on 60 mesh....	0.37	14.65	2.42
Passing 60 mesh....Held on 80 mesh....	0.22	15.28	2.59
Passing 80 mesh....Held on 100 mesh....	0.44	15.62	2.73
Passing 100 mesh ..Held on 200 mesh....	1.22	13.83	2.43
Passing 200 mesh......................	1.85	13.05	2.25

The following float and sink test of coal from the same bed shows also that a large portion of the sulphur can not be separated by mechanical means.

	Ash Per cent.	Sulphur Per cent.	
Raw coal	13.03	3.00	
Heavier than 1.45 sp. gr.....	54.22	8.64	
1.35 to 1.45 sp. gr..........	18.68	2.65	
Lighter than 1.35 sp. gr.....	7.11	2.13	
Pulverized raw coal....	12.9	2.80	
Heavier than 1.45 sp. gr.....	54.7	8.25......	11.02 per cent. weight
1.35 to 1.45 sp. gr..........	18 8	2.65......	3.18 per cent. weight
Lighter than 1.35 sp. gr.....	7.1	2.12......	85.00 per cent. weight

The mechanical arrangement of the jigs in a washery depends entirely upon the character of the coal. The specific gravities of the materials are to be primarily considered. The specific gravity of coal varies between 1.28 and 1.4, and that of the impurities usually lies between 1.5 and 3, or even higher in case of pyrites. If the specific gravity of the coal is close to or even overlaps in some instances the specific gravity of the impurities, we have a difficult problem on hand; but if there exists a considerable difference between the specific gravities of the two products the washing will become comparatively easy.

In the latter case simple pieces of apparatus are sufficient and one-compartment jigs can be used. In the first case, however,

separate jigs with two or even three compartments must be employed and rewashing must be considered. Furthermore, it must be determined whether or not the impurities are disseminated throughout the coal. In this case the difference between the specific gravities of the materials is more or less obliterated and rewashing is advisable if the middle product cannot be used at the mine. If the difference between the specific gravities of the materials is small and at the same time the impurities are disseminated throughout the coal, jigging in three-compartment jigs would be advisable.

Many variations of conditions exist, and it is difficult to predict which type of preparation equipment should be used. The arrangement of the jigs should be such that the flow of materials can be changed easily.

As to the actual performance of washers, it may be said in a general way that impurities lighter than 1.5 specific gravity are rarely separated by them to any considerable extent, and that a plant can be so designed as to eliminate practically all impurities heavier than 1.75 specific gravity and make a rejection of the larger portion of material between 1.5 and 1.75 specific gravity. There are few washers in operation, however, at the present time that are doing so well. Also, if the coal is not too fine there should not be more than 5 per cent. of coal in the refuse; and this amount will usually be less than 1 per cent. of the raw coal.

To show the efficiency of a washer, David Hancock, consulting engineer, has devised a chart upon which can be shown, graphically, the composition of the raw coal, washed coal and refuse. These are plotted to scale and show at a glance the comparative efficiency of different washers as determined from actual tests. A specimen of such a chart is shown in Fig. 72. It represents the working of a Stewart type of washer.

It is necessary to know first the composition of the raw coal. This is determined by separations made for each five points of specific gravity upon an average sample. On the left side of the diagram to any convenient scale are laid off the percentages found. For instance, in this case the sample contained 66.8 per cent. of coal lighter than 1.35 specific gravity; therefore, at the distance represented by this figure the dotted horizontal line is

drawn and marked 1.35 specific gravity. Also, the first class of impurity separated between 1.35 and 1.4 specific gravity was found to be 6.9 per cent. of the entire sample, and this distance is laid off to the same scale and marked on the chart.

After laying off the vertical scale in the same manner for the entire 100 per cent. of raw coal, the horizontal scale is then subdivided according to the per cent. of each class of impurity found in the washed coal as compared with the amount found in the

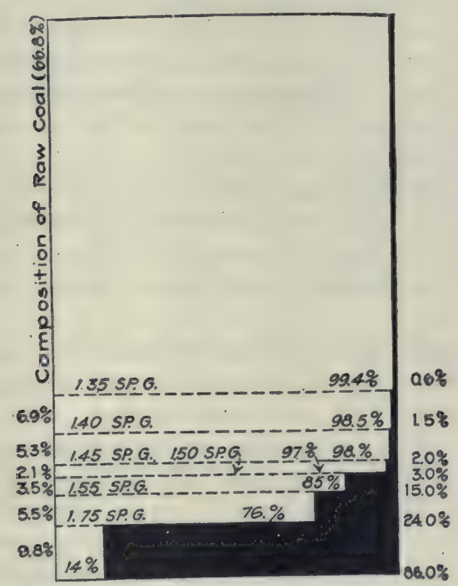


Fig. 72. Hancock's Efficiency Chart

raw coal. The balance, represented by the black area, is the rejection or refuse; both the quality and amount are indicated graphically, the areas being proportional to the weights of washed coal and refuse.

The figures to the right of the diagram show the amount of each class of impurity which goes to waste and the amount which is retained in the washed coal. For instance, it shows that 0.6 per cent. of good coal is wasted. It shows, further, that practically no separation of coal and impurities is made below 1.5 specific gravity, and that of the impurities heavier than 1.75 specific

gravity 14 per cent. is retained in the washed coal and 86 per cent. rejected. It should be noted in this connection that heavy impurities when retained in the washed coal are usually fine material that would pass through a ¼-in. screen. The rejection of slate heavier than 1.75 sg. is practically complete in the coarse sizes.

This chart can be called an "efficiency chart" of a coal washer and is applicable to any type of washer and any coal if the figures upon which it is based are accurately ascertained in any given case. In the case of the washer shown by the diagram, the ash of the raw coal was 15.94 per cent. and this was reduced by washing to 11.90 per cent., the coal being a difficult one to wash. The amount of refuse was 10.8 per cent. of the raw coal, and the yield was therefore 89.2 per cent.

One other type of graphical illustration of the washing process has been described by Pascal in the *Colliery Guardian* (Aug. 10, 1917). Messrs. Thomas Fraser and H. F. Yancey have made use of this graph for showing the difference between washable and nonwashable coal.[1]

The graphs here presented show the analysis of a washable coal before and after washing, and of this washable coal compared with a raw coal which is difficult to wash. The first graph, Fig. 73, shows very clearly what class of material is removed by washing. While particles heavier than 1.60 specific gravity were practically all removed, particles between 1.30 and 1.60 in specific gravity are not appreciably affected by washing. The analyses given in Table 24 show that this material is higher in ash and sulfur than is desirable in the clean coal, but lower than is desirable in the refuse. This represents a class of impurities difficult to remove, and is the product that appears at the washery as "true middling." If the specific gravity analysis of a raw coal shows a large percentage of this material it is very difficult to wash successfully. This condition is illustrated in the second graph, Fig. 74, comparing the raw coal of Fig. 73 with a coal much more difficult to wash. The total percentage between 1.35 and 1.6 specific gravity on the non-washable coal is 40 as compared with only 17 for the washable coal.

[1] "Some Factors that Affect the Washability of a Coal," by Thomas Fraser and H. F. Yancey.

ANALYSES OF COALS REPRESENTED IN FIG. 73

Specific Gravity	Raw Coal: Per cent. of total sample	Raw Coal: Ash, Per cent.	Raw Coal: Sulphur, Per cent.	Washed Coal: Per cent. of total sample	Washed Coal: Ash, Per cent.	Washed Coal: Sulphur, Per cent.
–1.30........	73.35	4.64	1.72	85.50	4.77	1.63
1.30 to 1.35........	8.74	11.27	2.14	8.30	11.8	2.06
1.35 to 1.40........	4.93	17.78	2.39	3.70	17.9	2.13
1.40 to 1.45........	1.82	20.32	2.52	0.88	18.5	2.36
1.45 to 1.50........	0.39	24.60	2.62	0.27	23.6	2.55
1.50 to 1.60........	1.12	29.90	2.80	0.54	28.3	2.84
1.60 to 1.80........	2.13	49.53	3.43	0.34	48.8	3.76
1.80–	7.52	84.04	13.63	0.57	80.3	7.07

TABLE 24

ANALYSES OF COALS REPRESENTED IN FIG. 74

Specific Gravity	Washable Coal: Per cent. of total sample	Washable Coal: Ash, Per cent.	Washable Coal: Sulphur, Per cent.	Non-washable Coal: Per cent. of total sample	Non-washable Coal: Ash, Per cent.	Non-washable Coal: Sulphur, Per cent.
–1.30........	73.35	4.64	1.72	55.9	10.1	2.91
1.30 to 1.35........	8.74	11.27	2.14	20.5	13.3	3.35
1.35 to 1.40........	4.93	17.78	2.39	11.8	15.4	3.45
1.40 to 1.45........	1.82	20.32	2.52	3.8	19.1	4.39
1.45 to 1.50........	0.39	24.60	2.62	1.8	22.5	6.18
1.50 to 1.60........	1.12	29.90	2.80	2.1	27.6	9.29
1.60 to 1.80........	2.13	49.53	3.43	1.1	42.7	13.30
1.80–	7.52	84.04	13.63	3.0	60.5	34.12

TABLE 25

The ideal coal for washing would be represented by a graph showing all the material concentrated in the parts heavier than

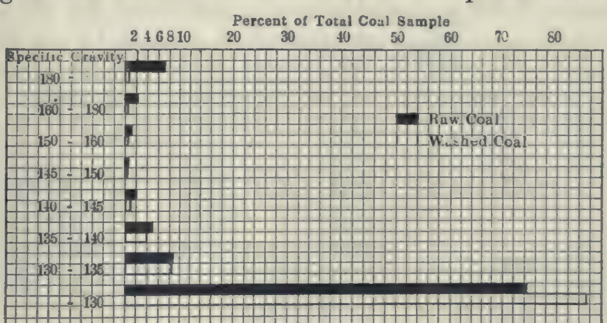


Fig. 73. Graph Showing Comparative Percentages of Material of Different Densities in a Coal Before and After Washing at 0–¼ in. Size

1.60 and lighter than 1.30. Results of a washing test on the coal represented in Fig. 73 are given in Table 26. Table 27 gives

the result of a test on the non-washable coal of Fig. 74. The specific gravity determinations on these samples were made by separating the sample at 1.30 specific gravity with the Delameter sink and float machine and treating the sink in a succession of

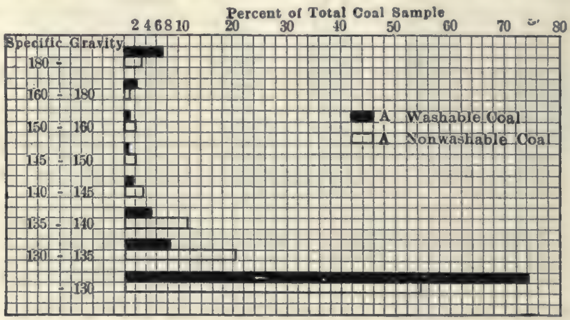


Fig. 74. Graph Showing Comparative Percentages of Material of Different Densities in a Washable Coal and a Non-Washable Coal, Both Crushed to ⅜ in. Maximum

heavier solutions in beakers. The effect of the conditions described on the results attainable by washing is shown by washing tests on some typical coals.

A Williamson County, Ill., coal is represented in Fig. 73 and Table 24 and is the washable coal of Fig. 74. The visible impurities consisted of pyrite bands and lenses as much as 1 in. in thickness; thin shale bands that hold together well in water; some fireclay; thin plates of pyrite in joint fissures; and an unusually large percentage of calcite and gypsum in the form of

Washing Test on a Coal from Williamson County, Ill.

				Sulphur				
	Feed, per cent.	Ash, per cent.	Reduction in Ash, per cent.	Pyritic, per cent.	Reduction in Pyritic, per cent.	Organic, per cent.	Total Sulphur, per cent.	Reduction in total Sulphur, per cent.
Raw coal ...	100.0	14.2		1.94		0.76	2.70	
Washed coal..	85.0	7.2	49	1.09	44	0.76	1.85	32
Middlings ...	6.6	19.8		1.80		0.76	2.56	
Washed coal and middling combined ..	91.6	8.1	43	1.14	41	0.76	1.90	30
Refuse	7.3	72.12					10.75	
Loss	1.1							

Table 26

thin sheets. This coal was washed at 0 to ¼ in. size on a table. The results are given in Table 26.

A coal from White County, Tenn., is represented in the graph of Fig. 74 as non-washable. A visual examination showed it to contain little clean shale or slate coarse enough to be liberated by crushing to the size at which coal is ordinarily jigged. Visible pyrite was present both as thin plates and as coarser bands or lenses. The difficulties in washing this coal were, as indicated by the graph, due to an exceptionally high percentage of material of intermediate density, indicating that the impurities are so fine that even when crushed to ⅜ in. size they are not liberated, and the exceptionally high ash and sulphur content of the lightest coal. The ash content of the part of this coal that was lighter than 1.30 in specific gravity was 10.10 while the corresponding increment of the washable Illinois coal analyzed 4.64 per cent. ash.

The Tennessee coal was crushed to ⅜ in. maximum size and treated on a washing table. Although a good reduction in sulphur in the clean coal was secured, it was made possible only by taking a very large middling product and a large refuse low in ash and sulphur. For these reasons the washing of this coal would not be profitable.

WASHING TEST ON A COAL FROM WHITE COUNTY, TENN.

	Feed, per cent.	Ash, per cent.	Reduction in Ash, per cent.	Sulphur				
				Pyritic, per cent.	Reduction in Pyritic, per cent.	Organic, per cent.	Total per cent.	Reduction in total Sulphur, per cent.
Raw coal ...	100.0	15.15		3.60		1.17	4.87	
Washed coal.	54.6	11.30	25	1.85	51.5	1.17	3.02	38
Middlings ...	32.0	17.90		4.04		1.17	5.22	
Washed coal and middling combined ..	86.6	13.80	9	2.65	29.00	1.17	3.82	21.5
Refuse	8.2	36.39					17.74	
Loss	5.2							

TABLE 27

To sum up the conditions that characterize an easily washed coal, the excess undesirable sulphur and ash should be present in form of shale or pyrite particles large enough to be detachable

from the coal, without crushing finer than ¼ in. in size. The coal, when crushed to the proper size for washing, should be separable by a sink-and-float test into an increment heavier than 1.6 specific gravity and an increment lower than 1.30 in specific gravity and low in ash and sulphur content with only a small percentage of intermediate density between these increments. The impurities that make a coal difficult to wash are thin bands of friable shale; bony coal; carbonaceous shale; thin filmlike flakes of pyrite, calcite, or gypsum in joint fissures; finely divided impurities intimately mixed with the coal, and organic sulphur.

The chief value, in coal-washing investigations, of the determination of organic sulphur by extraction of the sulphate and the pyritic sulphur, lies in finding a value below which there can be no reduction of sulphur content by mechanical processes. For example, if the coal from a given mine contains 3 per cent. of total, and 1 per cent. of organic sulphur, it would of course be impossible to expect a washed product carrying less than 1 per cent. of sulphur. Although this is a self-evident fact, it is of such importance in determining the washability of a coal that attention is directed to it. It would be inadvisable to give here a definite figure for the reduction in pyritic sulphur that can be expected with the best modern coal washing machinery. The data given indicate that, in some coals, one-half of the pyritic sulphur may be removed, but the percentage reduction would vary markedly with different coals, depending on the physical form in which the pyritic sulphur occurs. In any case, the minimum sulphur content that may be obtained in the clean coal is well above the organic sulphur content because some pyrite occurs in a very finely divided state intimately mixed with the coal. For practical purposes in coal washing this, in addition to the organic sulphur, may be considered as fixed sulphur.

In order to deduce a satisfactory method of calculating the efficiency of the washing process, attention must be directed to the actual practice. The object of washing the raw coal is to concentrate to the utmost the valuable ingredient (that is, the float particles), so that the washed coal shall be a high-quality fuel. It is, therefore, possible to determine for a washing plant the efficiency with which the quality of the material is improved. This is termed the "qualitative efficiency" of the process.

Obviously, where the washed coal was perfectly clean—that is, composed solely of float particles—the qualitative efficiency was 100 per cent. It is, however, highly probable that the plant, in delivering a small quantity of pure coal, was rejecting as refuse quite a large proportion of the raw coal. Evidently a considerable loss of float particles in the refuse was taking place. Therefore, a second conception is reached in that, for perfect washing, the plant must recover quantitatively all of the float particles so that none escape as refuse. The effectiveness with which the float particles are recovered is termed the "quantitative efficiency" of the plant.

Thomas James Drakeley has given in his paper entitled "Coal Washing, a Scientific Study," a method of combining the qualitative and quantitative efficiencies, so as to obtain a result that will represent the general efficiency of a coal washery. A simple case will make this method clear. Supposing that the washer receives 100 lbs. of raw coal containing 80 per cent. float and 20 per cent. sink particles, and delivers the products given in the following table:

Description	Raw Coal per cent.	Washed Coal per cent.	Refuse per cent.
Float	80	90 (76.5 lb.)	23.33 (3.5 lb.)
Sink	20	10 (8.5 lb.)	76.67 (11.5 lb.)
Output percentage.	100	85.0	15.0

TABLE 28

Qualitative Efficiency. The concentration of the float particles in the raw coal is 80 per cent., and in the washed coal 90 per cent. Hence the concentration is raised by 10 per cent. out of a possible 20 per cent. Therefore, the qualitative efficiency is

$$\frac{10}{20} \times 100 = 50 \text{ per cent.}$$

Quantitative Efficiency. In dealing with the raw coal, the plant rejects 15 per cent. of the weight as refuse—of which 23.33 per cent. is composed of valuable float particles. This means that float particles amounting to $\frac{15 \times 23.33}{100}$, or 3.5 per cent. of the

total output, are lost. But of the raw coal the valuable float particles only amount to 80 per cent. Therefore, the plant recovers 76.5 parts from a possible 80 parts. Hence the quantitative efficiency is $\frac{76.5}{80} \times 100 = 95.63$ per cent.

General Efficiency of the Washing Process. The process recovers 95.63 per cent. of the float particles with the quality improved by 50 per cent. Therefore, the general efficiency is

$$\frac{95.63 \times 50}{100} = 47.82 \text{ per cent.}$$

The foregoing cases are simple and in the following some of the more complicated conditions met in actual practice will be given.

QUALITY AND OUTPUT OF THE RAW COAL AND THE WASHED PRODUCTS FROM A WASHERY

Description	Raw Coal per cent.	Slack per cent.	Washed Coal Peas per cent.	Beans per cent.	Nuts per cent.	Refuse per cent.
Float	84.5	89.5	92	94	95	12.5
Sink	15.5	10.5	8	6	5	87.5
Output	100.0	25.0	23	22	20	10.0

TABLE 29

One hundred pounds of raw coal entering the washery will produce the quantities of washed coal shown in the following table:

CALCULATION OF THE PERCENTAGE COMPOSITION OF THE TOTAL WASHED COAL

Weight in pounds	Class	Weight of Float particles in pounds	Weight of Sink particles in pounds
25	Slack	22.38	2.62
23	Peas	21.16	1.84
22	Beans	20.68	1.32
20	Nuts	19.00	1.00
Totals 90		83.22	6.78
Percentage composition of total washed coal		92.47 per cent.	7.53 per ct.

TABLE 30

The concentration of the float particles in the raw coal is 84.5 per cent. and in the washed coal 92.47 per cent. Hence, the

concentration has been raised by 7.97 per cent. out of a possible 15.5 per cent. Therefore the qualitative efficiency is $\frac{7.97}{15.5} \times 100 = 51.42$ per cent.

The refuse, of which 12.5 per cent. is float material, amounts to 10 per cent. of the raw coal. Hence, from 100 lbs. of raw coal 1.25 lbs. of float material is lost in the refuse. Therefore, the process recovers (84.5 — 1.25) or 83.25 lbs. of the 84.5 lbs. entering the plant. Hence, the quantitative efficiency is $\frac{83.25}{84.5} \times 100 = 98.52$ per cent. Therefore, the general efficiency is $\frac{51.42 \times 98.52}{100} = 50.66$ per cent.

The qualitative efficiency of the different washing processes examined by Thomas J. Drakeley varied from about 25 to 75 per cent., and averaged 58.20 per cent. Mr. Drakeley, however, states that he considers that, where the qualitative efficiency fell below 65 per cent., it might have been raised to this value by making slight alterations in the working of the plant. Perhaps 60 per cent. might be deemed a good average working for trough washers.

The quantitative efficiencies averaged 97.89 per cent., and varied from about 91 to 99.8 per cent. The average value of 97.89 per cent. means that 2.11 per cent. of the coal is being lost. This value compares well with the loss sustained in ore dressing.

General Efficiency of the Washing Process. From observations it would appear that a general efficiency of about 65 per cent. should be considered average coal-washing practice; while 75 per cent. is certainly excellent working. The average value for 15 washers was 56.93 per cent. It will be seen that the values vary from 25.16 to 72.38 per cent. This enormous variation indicates that it is a matter of immediate importance to place the practice of coal washing under scientific control.

It is obvious from the foregoing examples that in order to calculate the general efficiency of the washing process the output must be known. In some instances it is not possible to get the

Formulae for Figuring the Efficiencies of a Coal Washery

Qualitative efficiency: $X = \dfrac{b\text{-}a}{100\text{-}a} \times 100$ per cent.

Quantitative efficiency: $Y = \dfrac{a - \dfrac{c \cdot r}{100}}{a} \times 100$ per cent.

General efficiency of the washing process: $\dfrac{XY}{100}$ per cent.

Where a is percentage of float particles in the raw coal
b is percentage of float particles in the washed coal
c is percentage of float particles in the refuse
r is percentage of the refuse.

correct weight, especially of the refuse. J. R. Campbell, chief chemist of the H. C. Frick Co., has developed a mathematical formula, whereby the percentage of the refuse and the washed coal can be easily ascertained from the analyses alone. Mr. Campbell calls the mathematical process an alligation alternate. The following example will explain this method: For instance, given the analysis of the raw coal, washed coal and refuse, it is comparatively easy to calculate the percentage of the refuse, thus:

Description	Raw Coal per cent.	Washed Coal per cent.	Refuse per cent.
Ash	14.48	6.98	55.42
Sulphur	3.53	2.41	10.40
Total impurities	18.01	9.39	65.82

Table 31

$$\begin{array}{lllll} & 9.39 & 8.62 & 47.81 & \dfrac{47.81}{56.43} \times 100 = 84.7 \text{ per cent. washed coal} \\ 18.01 \text{———} & & & & \\ & 65.82 & 47.81 & \dfrac{8.62}{56.43} & \dfrac{8.62}{56.43} \times 100 = 15.3 \text{ per cent. refuse} \end{array}$$

In a similar manner the percentage of refuse can be calculated from either the ash or the sulphur determination alone when accurately determined and the results should agree within reasonable limits. In general, the mathematical deductions are more accurate than the actual weights under ordinary conditions

of obtaining the latter. The underlying principle of "alligation alternate" can be readily formulated as follows:

Let C be percentage of ash in the raw coal, W that in the washed coal, and R be the ash in the refuse; then

$$\begin{array}{llll} & W & C-W & R-C \quad \dfrac{R-C}{R-W} \times 100 = \text{per cent. washed coal} \\ C & \multicolumn{2}{l}{\rule{5em}{0.4pt}} & \\ & R & R-C & \dfrac{C-W}{R-W} \quad \dfrac{C-W}{R-W} \times 100 = \text{per cent. of refuse} \end{array}$$

Or, inversely, $\dfrac{R-W}{C-W} =$ the ratio of elimination, and dividing 100 by this figure gives the percentage of refuse, and 100 per cent.—the per cent. of refuse equals the per cent. of washed coal. In a similar manner,

$\dfrac{(C-W)R}{(R-W)C} \times 100 =$ per cent. of elimination of ash or sulphur. Thus, in the example cited before,

$$\frac{(14.48 - 6.98) \times 55.42}{(55.42 - 6.98) \times 14.48} \times 100 = 59.3 \text{ per cent. elimination of ash}$$

$$\frac{(\ 3.53 - 2.41) \times 10.40}{(10.40 - 2.41) \times \ 3.53} \times 100 = 41.3 \text{ per cent. elimination of sulphur.}$$

The percentage of reduction of the impurities from raw to washed coal has been, and still is, frequently cited as a guide in comparing different washer efficiencies. It is certainly a very unreliable guide unless the washers which are compared are working upon the same coal. It will be evident to anyone upon a little reflection that the percentage of ash or sulphur reduction will depend more upon the nature and amount of the impurities in the coal than upon the different types of washers. I have before me figures showing an ash reduction from 21.50 per cent. in the raw coal to 4.50 per cent. in the washed coal, the work being done by a washer little, if any, better than the machine which made a reduction from 15.94 per cent. to 11.90 per cent., giving a reduction of 79 per cent. as against 25 per cent. The explanation is to be found in the difference in the amount and

character of the impurities in the coal from the two mines and not in any essential difference in the washers.

Another result might be cited where a washer identical with the one which produced a reduction of ash from 15.94 per cent. to 11.90 per cent. showed the following results: Ash in raw coal, 21.4 per cent.; ash in washed coal, 3.08 per cent., or a reduction of 85.6 per cent. It is of course absurd to suppose that any such difference could have existed between washers of identical construction, but the difference is simply due to the fact that the two coals contain impurities quite different in character and amount.

The usual guarantees given for the performance of a washery include the qualitative and quantitative efficiency, by specifying a maximum amount of "sink" in the washed coal and a minimum amount of "float" in the refuse. The amount of float in the refuse is either expressed as a percentage of the refuse or better still as a percentage of the total raw-coal treated. The material lighter than 1.35 sp. gr. in the refuse, usually called good coal, should never exceed 1 per cent. of the raw coal and in modern washeries working under scientific control is brought as low as ¾ per cent. of the raw coal.

This means, that in a washery treating 2,000 tons of raw coal per day of 10 hr., 15 tons of good coal are lost each day with the refuse.

The above holds good only for easily washed coal, containing little if any bone. The line of demarcation between good coal and refuse should not be too sharply drawn. A range of from 15 to 20 points in the specific gravity ought to be interposed between good coal and refuse, so that a guarantee should read as follows: The washed coal shall not contain more than . . . per cent of material heavier than 1.50 sp. gr. and the refuse shall not contain more than . . . per cent. of the total raw coal of any material lighter than 1.35 sp. gr.

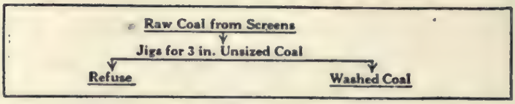
CHAPTER XVII

DIFFERENT METHODS OF WASHING COAL

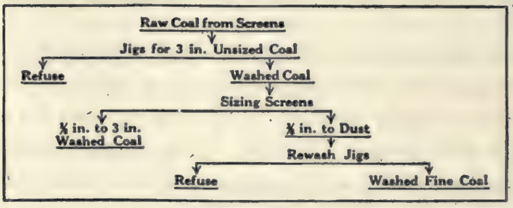
Besides the character of the raw coal, which represents the base upon which the washing of the coal must be established, the type of the washing methods to be chosen must be considered. The rules for the proper selection of these methods have been given previously. They are in close relation with the mechanical equipment of the jigs. According to the washing processes and the construction of the jigs, several main types of plant can be established. These are shown in the accompanying flow sheets.

In regard to the flow sheets shown, the following remarks may be made: The system of rewashing according to Type IV can in some instances also be used when the character of the raw coal itself does not require such rewashing. But when it is desirable to be independent of the human factor and the continuous care of the operator, especially when the washed coal must be exceedingly clean and is sold under strict specifications, the coal is washed very closely in the primary jigs and the resulting unavoidable loss of good coal in the refuse is recovered in the rewash jigs.

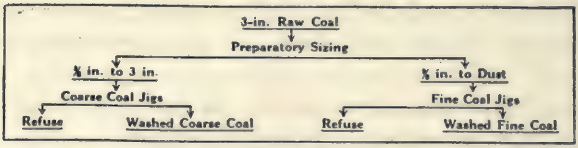
In Type VI the rewash jigs for the middle products of the primary jigs could be located ahead of the recrushing plant. This transposition should also be considered in Type V, and its advisability will depend much upon the character of the middle product. If this contains a considerable amount of slate, picking tables can be used for the purpose of removing the heavy, pure slate, which when crushed would interfere with the proper operation of the rewash jigs. The foregoing types can be changed to suit local conditions. Only the most typical cases have been selected.



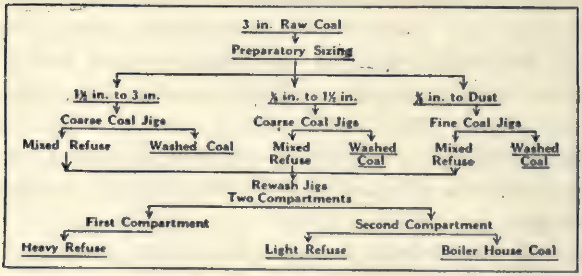
Type I



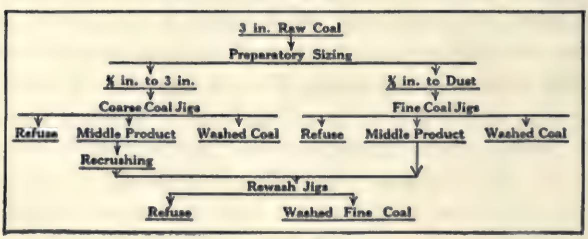
Type II



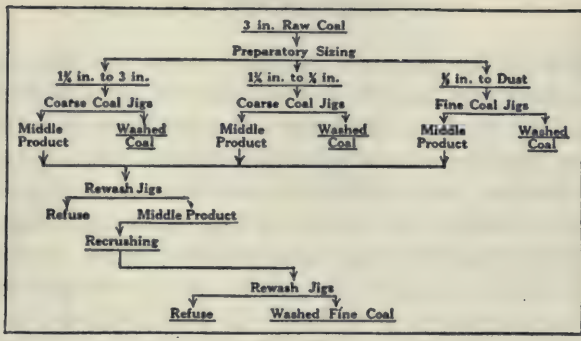
Type III



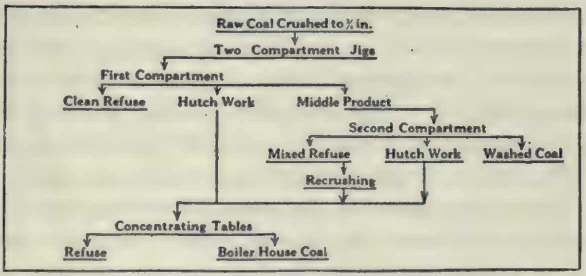
Type IV



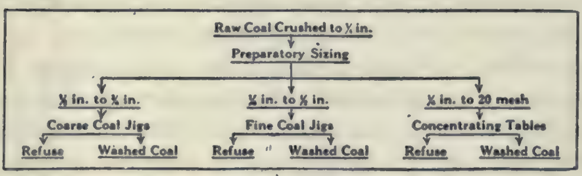
Type V



Type VI



Type VII



Type VIII

CHAPTER XVIII

THE FEEDING OF THE JIGS

The raw coal is fed to the jigs direct from the raw coal elevator if unsized coal is to be washed; and if the coal is sized before washing, from the discharge chutes of the screens either by means of gravity chutes or in sluiceways with water. This method, however, has been largely abandoned and modern washers have in the rear and above the jigs small equalizing bins to further secure an even and uninterrupted supply of coal to the jigs. It is also advisable to feed the coal to the jigs by means of mechanically operated feeders. In most installations the flow of coal into the jigs is merely regulated by a slide gate. This, however, does not give an even feed, especially with coarse coal.

The simplest and best type of feed is a slowly revolving drum with a slightly corrugated surface. The speed of the drum should be adjustable. This is accomplished most easily by means of a ratchet wheel and pawl, actuated from the jig eccentric shaft. Provision should be made whereby the pawl may be caused to cover a greater or less number of teeth on the ratchet wheel so that the drum will revolve faster or slower as desired. Shaking or oscillating apron feeders are also in use, but these are more complicated, take up more room and cannot be adjusted with such nicety as the revolving drum feeders.

The coal from the feeders should flow into the jigs in such a way that it will be discharged below the surface of the water, so that all the coal is totally submerged. For fine and dry coal it is advisable to spray the coal before it enters the jigs, to prevent the formation of dry lumps.

CHAPTER XIX

TYPES OF JIGS

It has been previously remarked that the construction of the jigs depends upon the character of the material to be washed. The jigs can be divided into three main types—coarse coal jigs, fine coal jigs, and jigs for unsized coal. According to the flow sheets, we find also jigs making only two products—that is, refuse and clean coal—and jigs making three products such as clean refuse, middle product and clean coal; or refuse, hutch work and clean coal.

Jigs can also be classified according to the means used to produce the pulsation of the water. Thus there are machines where the whole jig basket is moved up and down, and jigs with stationary screens in which the pulsation of the water is produced either by a plunger or by means of compressed air; or as in the Richard pulsator jig, by hydraulic shocks. The plungers can also be arranged differently. They may be located either in a separate compartment, which again can be placed in the rear of the jig compartment, or on one or both sides of the screens. We also have jigs with the plunger directly underneath the screen. One type of jig, with the plunger placed in a vertical position below the screen has, however, been proved a failure.

The jig screens are usually made of perforated steel plate; cast-iron grate bars are also sometimes used. The method of fastening the screen plates shows numerous variations. The methods used for refuse discharge are too numerous to mention, but they can be broadly divided into plain slide gates, either adjustable in a vertical position or swinging outward; double gates, in which the lower gate regulates the height of bed and the upper gate regulates the outflow of refuse; revolving slate valves; kettles or pot valves and, finally, discharge of refuse through an artificial bed.

Furthermore, jigs can be classified as one, two or three com-

partment machines. If we consider that in addition to the differences mentioned in construction jigs can be built either of wood, steel plates, cast-iron plates or even of reinforced concrete, and that the plungers can be actuated by fixed or adjustable eccentrics or by means of crank-arm mechanisms, and that each single type of each group can be used without great changes in any other group, we get so many varieties that a systematic classification of the jigs into distinct types is almost impossible. By considering, however, so far as is feasible all the important

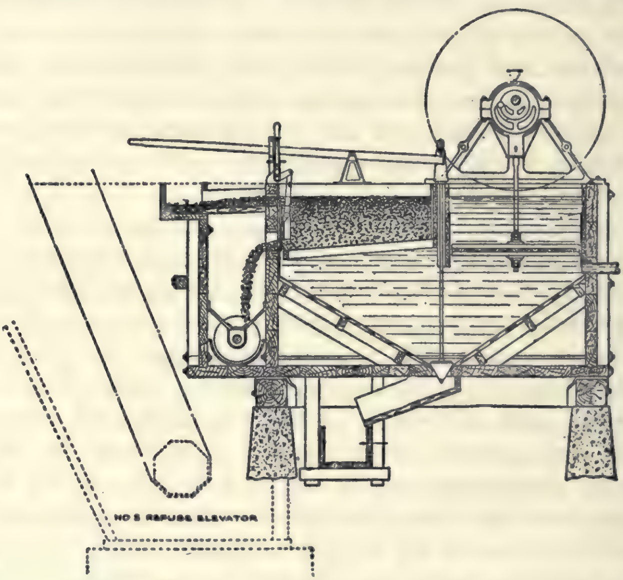


Fig. 75. Lührig Nut Coal Jig

differences, we can distinguish the following three general types:

Jigs with Fixed Screens—These include (a) coarse coal jigs, making two products only—refuse and washed coal. The plungers are in rear of the jigs, actuated either by fixed or adjustable eccentrics or by a crank-arm mechanism giving a differential motion. (b) Fine coal jigs with an artificial bed. These have the same plunger arrangement and drive as those of class (a). Refuse is withdrawn from the hutch and washed coal overflows at the front of the jig. (c) Coarse coal jigs with plungers underneath the screens. Either eccentric or crank-

arm mechanisms are employed for giving the plunger motion. The refuse is discharged and the washed coal overflows. (d) Jigs with plungers on both sides of the screen. The plunger motion may be like that in type (a). These machines have either simple refuse and washed coal discharge or a third discharge for middle product. This type is chiefly constructed as two- or three-compartment jigs. (e) Jigs with one plunger between compartments. This type is hardly ever used. (f) Jigs without plungers. The pulsation is actuated by puffs of compressed air or by hydraulic shocks.

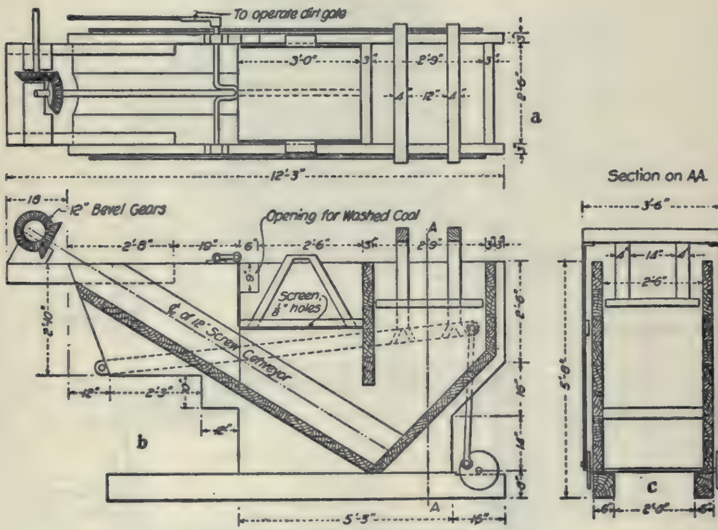


Fig. 76. Forrester Jig

A great variety of jigs with fixed screens, treating coarse (nut) coal were developed from the "Hartz" type of jig. The following descriptions and illustrations will show clearly the most typical constructions.

(1) The Lührig nut coal jig is a single-compartment machine whose plunger is given a simple reciprocating motion by means of an eccentric. The jig of this type shown in Fig. 75 consists of a rectangular box with hopper bottom having a partition in the middle, extending about half way down from the top, or to a point slightly above where the hoppering begins. Upon one

side of this partition is a relatively close fitting rectangular plunger actuated by an eccentric. On the other side of the partition there is a fixed screen slightly inclined away from the partition. The jig is filled with water, to which the plunger imparts a pulsating motion, forcing it up and down through the screen. Sized, raw, nut coal is fed upon the screen near the partition and purified by the hindred settling action induced by the pulsation of the water through the screen. The washed

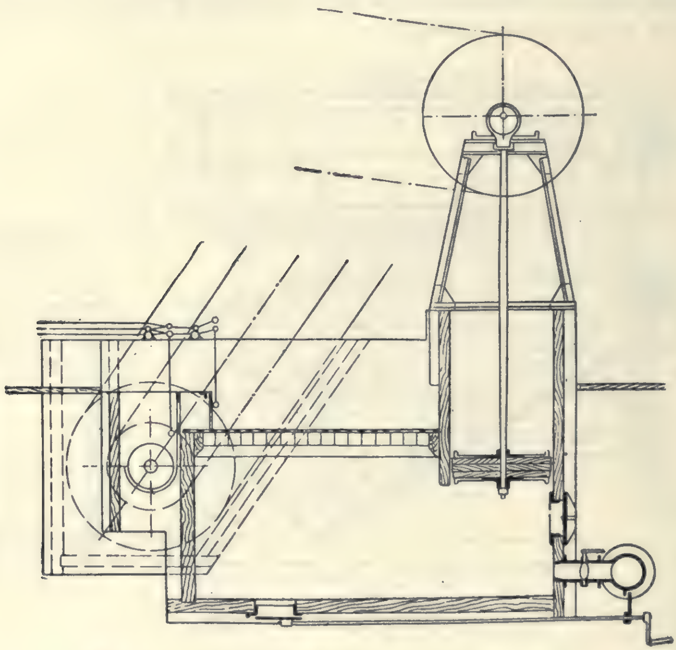


Fig. 77. Nut Coal Jig with Double Slate Gate

coal flows from the top of the screen compartment at the opposite end from the feed, while the refuse works its way across, assisted by the slope of the screen, and the excess over that required to maintain a suitable bed is discharged through a gate just above the screen and below the washed coal overflow. The bed is kept thin enough to permit regular and even pulsations of water through the screen, and thick enough to prevent fine coal from working through by the aid of suction and entering

the hoppered bottom, or hutch, of the jig. The refuse which collects in the hutch is discharged at intervals, as required, through a gate at the bottom.

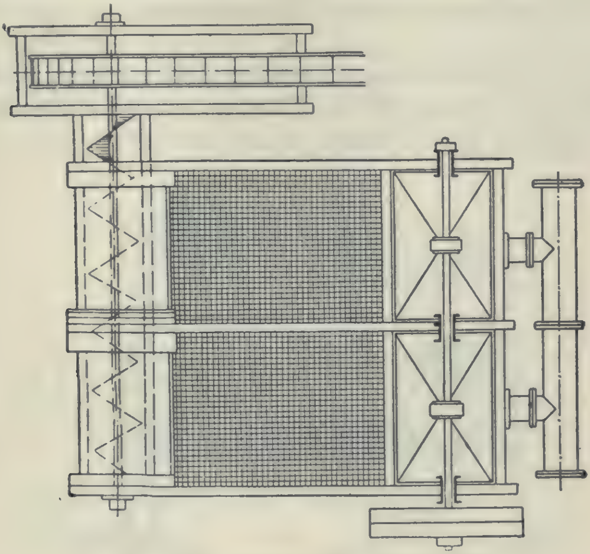


Fig. 78. Nut Coal Jig. Top View

(2) The Forrester jig is shown in Fig. 76. This jig is similar in construction to the Lührig machine. The plunger is

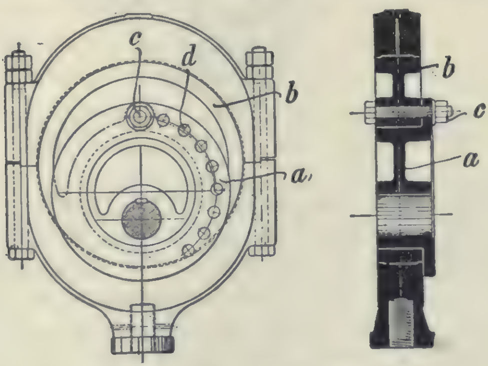


Fig. 79. Adjustable Eccentric

actuated by means of a crank and walking beam. The drive shaft is located below the jig and the refuse is carried away by

means of a screw conveyor. The jig screen is 30 by 36 in., and is perforated with 7/16 in. round holes. The jig has a rated capacity of 25 tons of 2½ in. screenings per hour. The plunger makes 6 in. strokes at a rate of 40 per minute.

Figs. 77 and 78 show a nut coal jig built of wood. This machine is used extensively in Europe. It has a double gate for the removal of the refuse.

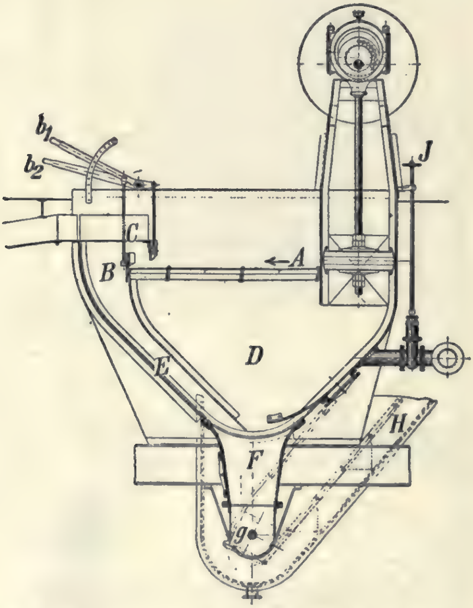


Fig. 80. Nut Coal Jig Built of Steel Plate

Fig. 80 shows a nut coal jig built of steel plate.

The raw coal is fed on to the jig at "A" and is carried forward in the direction of the arrow. The clean coal overflows over the plate "C." The refuse is discharged at "B" and its removal can be regulated by the gates "b_1 and b_2." The refuse from several jigs is collected at "g" and carried by a screw conveyor to the refuse elevator "H." The hutch work drops through "F" into the same conveyor as the refuse. The wash water can be regulated by a valve "J." The plunger

is actuated by an adjustable eccentric. Fig. 79 shows the construction of this eccentric.

Figs. 81, 82 and 83 show a nut coal jig with differential motion of the plunger by means of a crank arm mechanism.

This mechanism imparts to the plunger a quick and sharp down stroke and a slow up stroke. This causes a lively loosening up of the material on the jig screen during the down stroke

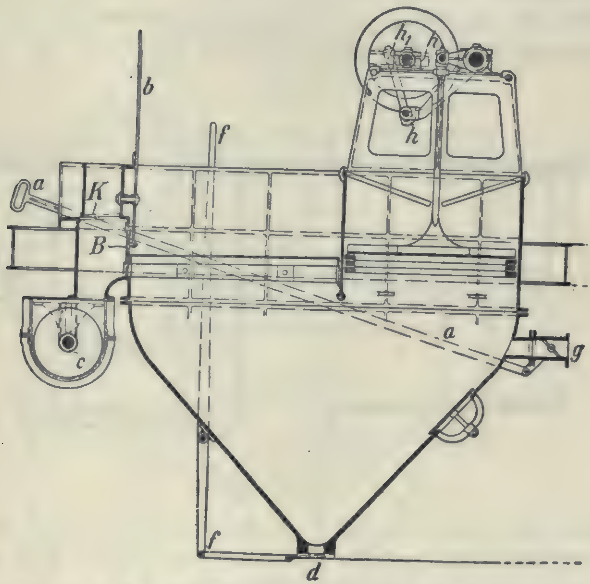


Fig. 81. Nut Coal Jig with Plunger Actuated by a Crank Arm Mechanism

of the plunger and a slow settling of the particles during the up stroke. The operation of this jig is greatly simplified by having all the regulating levers close together and within easy reach of the operator. The wash water can be regulated by the butterfly valve "g" operated by the pull rod "a." The lever "b" regulates the refuse discharge and the lever "f" opens and closes the gate "d" which regulates the discharge of the hutch work.

The Elmore jig is the outcome of 17 years of development. It has grown from a comparatively small machine of light con-

struction to the largest and heaviest coal jigging device of its type. The changes that have been wrought have all been the result of real experience with all kinds and conditions of coal. The result has been that this jig will stand continuous operation under the heaviest loads and will automatically make uniform products of clean coal and clean refuse.

The power required to operate this jig varies somewhat, depending on the size of coal fed to it. The finer sizes require a shorter plunger stroke, hence less power. The power required to operate the jig alone, not taking into account any provision for transmission machinery, will vary from 10 h.p. for the

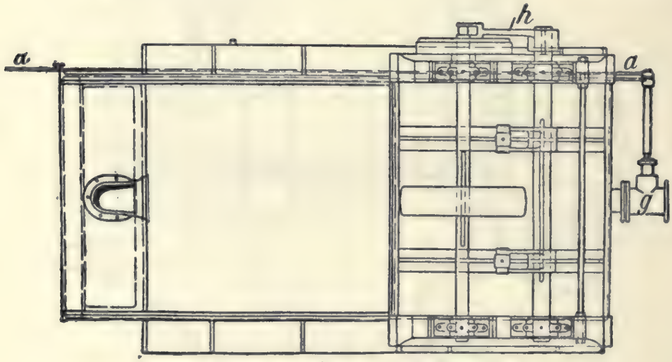


Fig. 82. Top View of Jig

finest sizes up to 13 h.p. for 3 in. nut. To this must be added the transmission loss, which when the usual main and countershafts are used, will probably be from 2 to 3 h.p.

If direct drive can be provided, it has been found that silent chain is far more satisfactory than gears. The standard jig is equipped with a pair of 36x8 in. tight and loose pulleys for driving the main jig shaft. The tight pulley weighs approximately 750 lbs., and has a balance wheel effect, which gives an even motion to the plunger stroke.

The "600-A" coal jig (as the machine shown is designated) consists of a tank with a partition (48) extending part way down into it. (Fig. 84.) On one side of this partition is a plunger (35) which is given a reciprocating motion. On the other side is a sieve or grate (13). In front of the grate is a

dam (38) over which all water and coal must pass when they leave the jig, flowing away on the overflow plate (25 Fig. 84 or (1) Fig. 87). The tank is filled with water up to the level of the top of the dam (38) and covers the plunger (35).

Each downward stroke of the plunger will, therefore, force or pump a volume of water upward through the sieve (13)

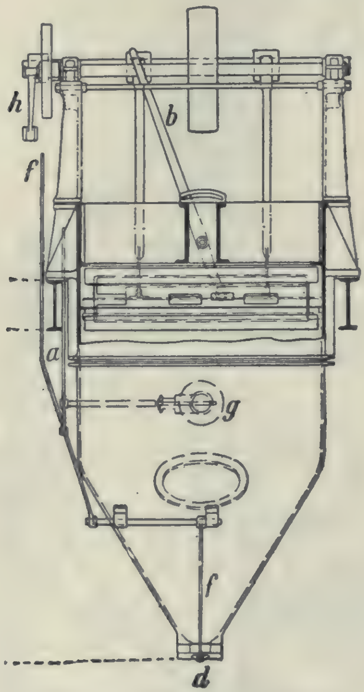


Fig. 83. End View of Jig

equal to the amount displaced by the plunger stroke. Raw coal containing pure coal, bone and the heavier refuse is fed to the jig between the feed plate (37) and the partition (48, Fig. 84) and falls on to the sieve (13). The pulsation of the stroke will now draw this raw coal under the opening at the bottom of the feed plate and make a level "bed" all over the sieve. This will continue to fill up until the top of the dam

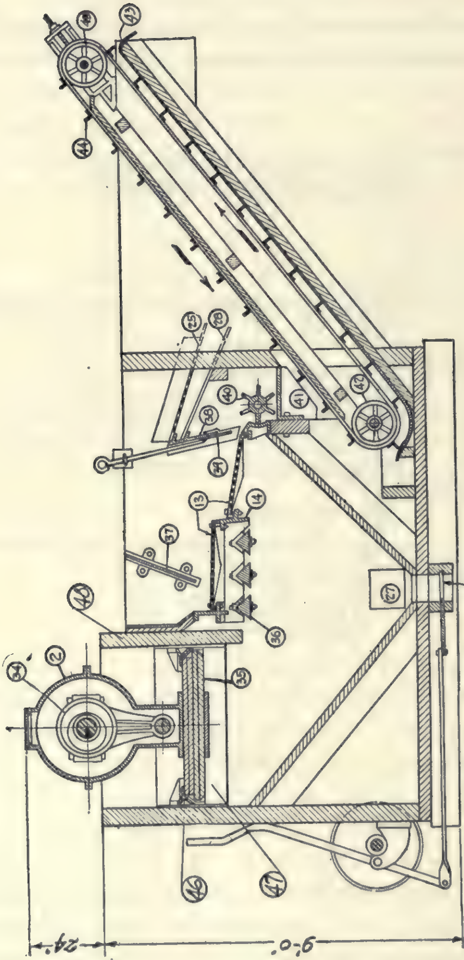


Fig. 84. Elmore "600-A" Coal Jig. Sectional Elevation

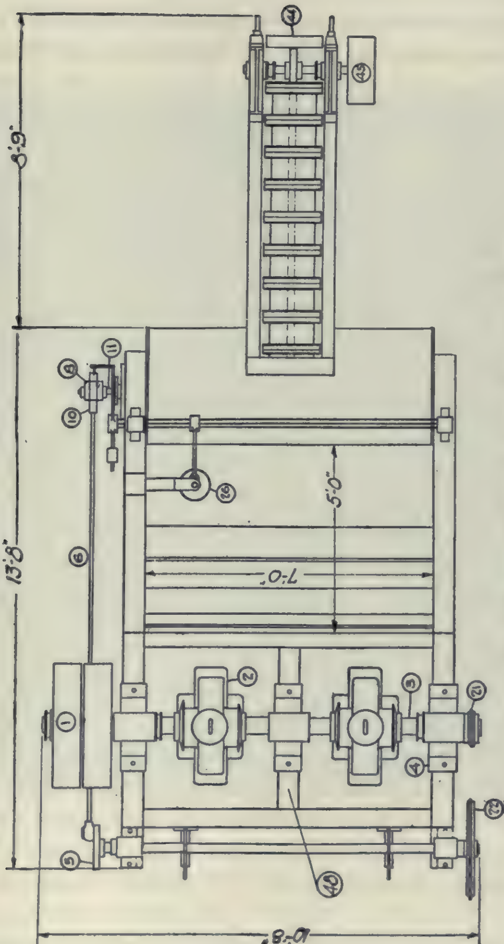


Fig. 85. Elmore "600-A" Coal Jig. Top View

(38) is reached, when both water and clean coal will flow over on plate (25).

While this filling up of the bed has been taking place, the pulsations of the stroke have caused the light coal to go to the top of the bed and the heavy particles of refuse to settle to the lowest strata on the sieve and form the "bottom." This separating process continues until the bottom has accumulated to a depth equal to about one-half the height of the dam (38); in other words, until about one-half the material in the bed is coal or light and the other half refuse or heavy. The "bone" that may be present in the feed will arrange itself in the middle zone, between the refuse and the pure coal. A constant supply of water must be furnished the jig, preferably by a large pipe entering the tank under the plungers. When the slate or refuse has accumulated to the thickness above mentioned, all further refuse that comes into the jig must be immediately removed, otherwise the "bottom" will get too thick and refuse will go over the top of the dam with the washed coal. The means by which this refuse is removed will be fully described in the following paragraphs.

As fast as the refuse is withdrawn, it is removed from the tank by the drag conveyor (44). Any fine refuse that may go through the holes in the sieve will collect in the "hutch" of the jig (the hopper in the tank under the plungers and the sieve). These fines are removed from time to time by opening the slush gate (29).

A jig tank must carry not only the pressure of the water that it holds, but it must be rigid enough to carry the weight of the heavy machinery mounted on and in it, as well as the added pressure due to the pulsations of the plunger. These pulsations come at the rate of approximately 100 per minute and unless the walls of the tank are made quite rigid, they will "breathe" with each stroke of the plunger. This will quickly destroy the tank.

The best type of jig tank, if made of wood, is one in which the walls are built up by spiking down flatwise, pieces of 2 x 6 in. cypress tank stock, surfaced on four sides to 5⅝ x 1¾ in., letting all corners and intersections alternately overlap, and placing two strands of candle wick between each layer and in all verti-

cal edge joints. The spikes, not smaller than 20 d, are driven about 8 in. apart, staggered, and close to the edges, with the candle wick running between the two rows.

To further strengthen the tank, vertical rods, some of them 1¼ in. in diameter, pass through from the top to the bottom of the sills. Others pass through the tank horizontally at places which receive the greatest stress from the pulsating action be-

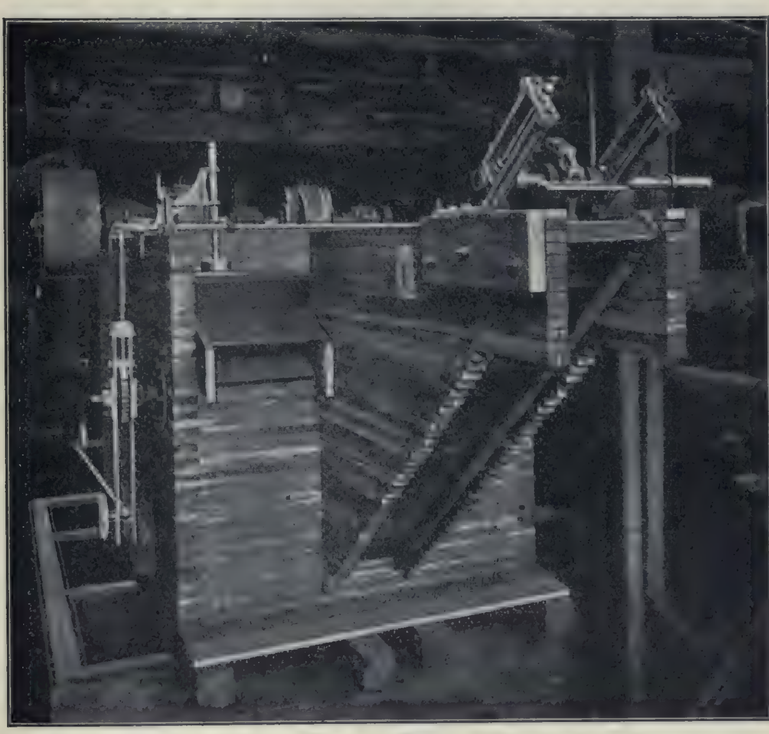


Fig. 86. Front View of Elmore "600-A" Coal Jig

fore referred to. The construction of the tank is shown in Fig. 86. The combined effect is to make a jig tank practically non-rotting (being built of cypress) and as rigid as a concrete wall. After the tank has been filled with water for 24 hr., all leaks will disappear.

The main shaft (3 Fig. 85) carrying the eccentrics which produce the jigging stroke, is 4 7/16 in. in diameter. It revolves at

100 r.p.m. in extra heavy bearings, mounted on sole plates (4) of special heavy design. Having in mind the fact that the work of the plungers is all done on the downward stroke, it will be seen that the pressure on the bearings and sole plates is all in the upward direction. Hence the bolts which secure these parts, the caps to the bearings and the castings, must be much heavier than is usually required for shafting of this size. All these details have been carefully worked out.

This main shaft carries two eccentrics (34 Fig. 84) each incased in a housing (2). These eccentrics act in unison and are fitted in such a manner that the stroke can be adjusted from zero up to 4 in. The eccentrics are connected to the housing by the wrist pins at the lower end of the arms on the under halves of the eccentric straps. The housings are bolted to the plungers (35 Fig. 84) and by a system of self-oiling internal guides, are given a true, reciprocating motion. The housings carry a quantity of oil in which the eccentric straps are constantly submerged.

Two eccentrics, each acting with its own plunger, are used for the reason that one plunger would be too long and heavy for convenient handling and stroke adjustment. It will be noted that the wall between the two plungers extends down into the tank only far enough to hold the rubbing plates (47), which surround the plungers. This center wall (48) also affords a good foundation for the center shaft bearing with its sole plate. The eccentrics and housings are of heavy design.

The length of stroke required to produce the best jigging action (the supply of water being sufficient) varies with the size of raw coal fed to the jig. With coal which has been passed through hammer crushers (as is frequently done when it is to be used for making metallurgical coke), and reduced so fine that 40 to 60 per cent. will pass through an ⅛ in. round hole, the stroke is not more than ⅞ in., for nut, it will vary from 1½ to 2 in., for egg from 2 to 2½ in., and for material which will pass through a 5 or 5½ in. round hole, the stroke will approximate 3 in.

The plungers (35 Fig. 84) are made of four layers of 2 in. oak plank, surfaced on all sides. Around the top edge on all four sides is bolted a heavy casting (46), to which is bolted 6-ply rubber belting, 6 in. wide, and extending downward and out-

ward in such a manner that the lower edge of the belting comes in contact with the rubbing plates (47). Above this point there is ample space for the water to pass freely between the walls of the compartment and the plunger. This piece of rubber belting, therefore becomes a flap valve, which closes on the downward stroke and opens on the upward stroke. This produces almost a theoretically perfect jigging effect in the bed of coal and refuse resting on the sieve (13) opposite the plunger.

On the downward stroke the valve closes and forces all the water displaced by the plunger, up through the bed, where it does its work of separating the coal from the refuse. With a plunger not equipped with these flap valves, much of the water displaced passes up around all four sides to the top of the plunger, doing no work of separation. Such jigs require much longer stroke.

On the upward stroke of the plunger, these flap valves yield immediately, and break all tendency to form a vacuum under the plunger. It is a cardinal principle in the art of jigging, either of ore or coal, that suction in the bed of the jig must be avoided. The forming of a vacuum under the plunger, on the upward stroke, is detrimental to the jigging action and has a tendency to undo the good work performed in the bed while the plunger was on its downward stroke.

By referring to (13) Fig. 84 and (2) Fig. 87 the two forms of perforated screens held rigidly in place, on which the bed of coal and refuse rests, can be easily seen.

For coarse sizes the form shown in Fig. 84 is usually employed. It is formed of cast-iron grates made in segments 12 in. wide, and securely bolted to the rests which extend entirely across the width (7 ft.) of the jig bed. These heavy rests are bolted to the walls of the jig tank.

For fine sizes such as slack the construction shown in Fig. 87 is used.

The sieve (2), which is of perforated plate either steel or bronze (depending on the acid in the water), is securely bolted to the heavy cast-iron supports (3) which extend from wall to wall and rest on the pieces (9) which are bolted to the tank. The holes in this plate are usually quite small, ⅛ in. round

being the average size, although 3⁄16 in. and ¼ in. are sometimes better. The size of these holes is gaged by the amount of fines in the refuse. It is not advisable to let too much fines pass through these holes into the hutch of the jig.

Note the triangular pieces (36, Fig. 84, and 4, Fig. 87), under the grate or sieve at the back, or feed side. These are pieces of 6 x 6 in. oak, sawed diagonally from corner to corner and secured by bolts at the ends to castings which in turn are bolted to the tank walls, as shown. These triangular pieces perform an

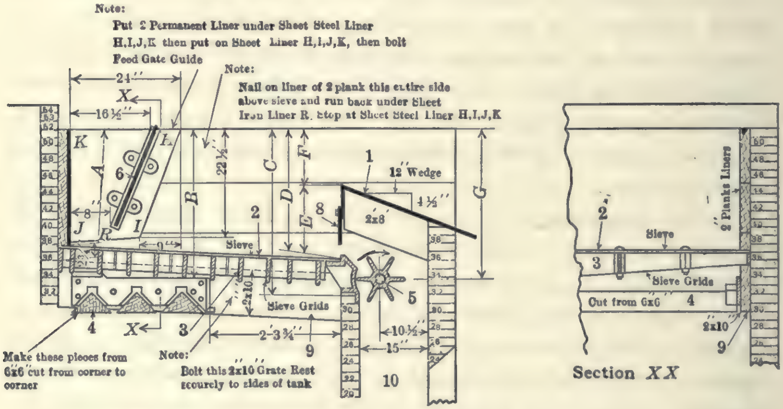


Fig. 87. Arrangement of Jig Screen for Fine Coal

important service. When the plunger makes its downward stroke and forces the water up through the perforated grate or sieve, the tendency is for the larger portion of this water to take the path of least resistance and go up through the back side of the sieve, near the feed plate (37, Fig. 84, or 6, Fig. 87), leaving the front end of the bed in the region of the discharge for both coal and refuse, with little jigging action. These triangular pieces act as a resistance to the free flow of water upward through the sieve above them, and force a proper proportion of the water toward the front part of the bed, thus producing uniform jigging action over the whole area of the bed.

Reference to 1 Fig. 87 will show the form of overflow plate used for bituminous coal containing slack sizes. This plate extends across the 7 ft. width of the jig, and gets its name from

the fact that the washed coal and all the water used in the jigging process flows over this plate. From this plate they both pass to the main washed coal settling tank. This may be of various kinds but is a part of every properly designed coal washery. The upper end of this plate is bent downward to a vertical position and to this portion is bolted the adjustable plate (8) for regulating the width of the opening underneath, where the refuse passes to the rotating refuse valve (5). The size of the opening does not in any way regulate the amount of refuse which is discharged. It is simply set wide enough to permit the easy passage of any piece of refuse which properly can come to the jig. As will be shown the amount of refuse removed is entirely controlled by the rate of rotation of the valve (5).

When the raw coal fed to the jig, is a sized product with all the slack taken out, it is usual to employ the overflow plate construction shown in Fig. 84. Here two plates are used, one (25) being perforated with long slot holes large enough to allow all the water to drop through on the solid plate (28). This both dewaters and rinses the washed coal at the same time. If it contains any small slime coal as a result of bad screening or abrasion in the bed, this is washed off and goes with the water, leaving the sized, washed coal clean and bright. The water which falls on the plate (28) passes immediately to the slack coal dewatering tank, where the coal is removed and the water re-used in the jig.

Various types of equipment are used to remove the refuse from the bed of coal-jigging machines. They are divided into two classes: The pot valve, or pocket and the long rotating valve or gate. The former are openings from 12 to 24 inches apart in the bed of the jig placed near the discharge end, with devices which are intended to prevent the coal from getting into them. Refuse coming into the jig must find its way to these pockets, and in order to reach them, the most of it travels diagonally to the flow of the coal and the water. In other words the opening for the discharge of refuse does not extend entirely across the jig bed thereby allowing each piece of refuse to take its direct and natural path to it, but each piece of refuse must find the special holes, located many inches apart,

through which it can escape. Inert refuse remains on the screen between the pot valves reducing thereby the jigging area.

The Elmore Automatic Jig Control. Beginning as a rather complicated, electrically controlled device, the Elmore automatic control as now built as shown in Figs. 88, 89 and 90. Fig. 88 shows the section transversely across the jigging compartment, just behind the overflow plate (14) and directly through the float cylinder (1). Fig. 89 is a side elevation of the front end of the jig, showing that portion of the tank and equipment where the overflow plate, the automatic control device and the mechanism for actuating the refuse valve are located. Fig. 90 shows a plan of the jigging compartment.

To the overflow front casting (14) is bolted the float cylinder (1). This is 10 in. in inside diameter and 22 in. high, open at both ends. The bottom is placed 3 or 4 in. above the jigging sieve, which brings it below the level of the top layer of refuse (20) which it is desired to maintain on the sieve. On top of the layer of slate, will accumulate a layer of clean coal (22) to a height and thickness up to the top of the overflow front (14) where the clean coal with the water used in jigging will overflow onto the plate (15). For treating slack, this is made solid, but for jigging nut or coarser sizes, it is perforated, allowing the water to go through and accumulate on plate (16). Inside the float cylinder is the flat cast iron disk (21) carried at the lower end of the pipe guide (2). Attached to this pipe guide is the arm (24) which at the other end is fixed to the square shaft bar (4), carried in the bearings (3). At the end of this shaft, which extends out over the wall of the jig, is the double arm (5). One end of this arm carries the counterweight (10) and the other end is connected with the rod (6) in such a manner that it can lift the pawl (8). This pawl is a part of an oscillating mechanism mounted on the shaft (11) which forms the stem of a rotating valve for drawing off the refuse. This valve extends entirely across the jigging bed which in this particular machine is 7 ft. wide.

The refuse passes through the opening below the adjusting plate (17) and lies against the flights of this rotating feeder type of valve. As this valve rotates, the refuse is withdrawn

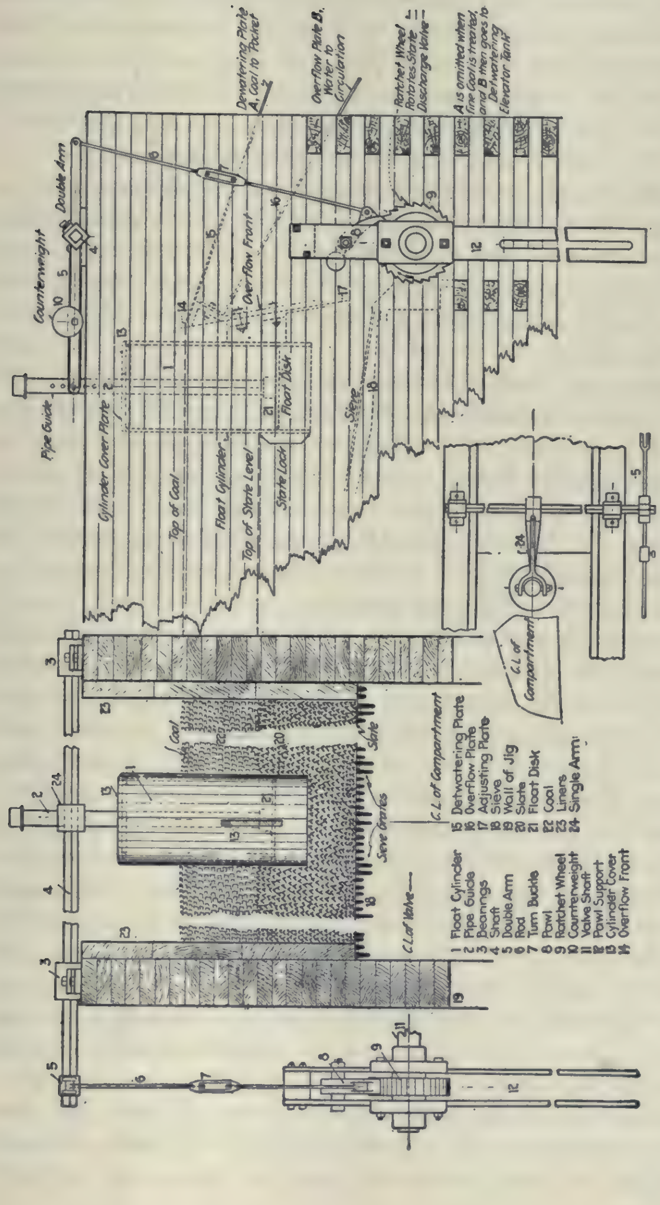


Fig. 88
Transverse Section

Fig. 89
Side Elevation

Fig. 90
Top View

Elmore Automatic Jig Control

from the jigging sieve and falls on a sloping board in the compartment underneath, whence it runs by gravity to the refuse drag conveyor which removes it from the jigging tank. The constant oscillating motion of the arm (12) is given by the crank (5) and connecting rod (6, Fig. 85), the crank being driven from the main jig shaft by suitable sprockets and chain. Keyed to the valve stem (11) is the ratchet wheel (9).

It is evident that when the pawl is down and the arm (12) is oscillating, the ratchet wheel (9) is rotated in the direction of the arrow as shown, and that when the pawl (8) is raised and not allowed to engage with the teeth, no rotation of this ratchet will take place, inasmuch as the bars (12) simply ride on the shaft (11) and are not keyed to it.

The automatic control of the rotation of the refuse valve is, therefore, entirely a matter of permitting the pawl to engage the teeth and rotate the valve whenever the level of the slate or refuse has reached the proper thickness on the jigging sieve. Conversely, the rotation of the valve and the removal of refuse ceases when the level of the bed of refuse has been lowered to the desired point. This is readily accomplished by the equipment shown in the following manner:

As the refuse accumulates on the jigging sieve, it will find its way up into the float cylinder (1) from the bottom end and will impinge on the bottom side of the float disk (21). At each stroke of the jigging plungers this float disk will receive a corresponding impact from the refuse as it is driven upward from below, and the whole structure of the float disk, the pipe guide, as well as the arm and counterweight will have a reciprocating movement with a few degrees of angular rotation of the shaft (4). This upward and downward movement is conveyed to the pawl (8) which readily oscillates on the bolt holding it in position between the arms (12). By adjusting the counterweight (10) to properly balance the effect of the upward pressure of the slate on the bottom of the float disk, an equillibrium is quickly produced whereby this float disk is maintained at a certain level in the jigging bed.

Whenever additional slate comes on the jig, the float disk will be raised within the cylinder and this will lower the connecting rod (6) and permit the pawl to engage the teeth of

the ratchet (9) instantly rotating the valve and removing the refuse through the orifice under plate (17). This lowers the level of the refuse on the jigging sieve and permits the float disk to sink to a lower level, when the pawl will again be lifted to a height not permitting it to engage the teeth of the ratchet. The withdrawal of refuse will thus be instantly stopped. When nothing but clean coal comes on the jig, or when the feed is entirely stopped, the pawl will accordingly be entirely disengaged and no refuse will be removed. This condition is not temporary, but will continue no matter how long the jig is run.

It is remarkable how accurately this simple device controls the level of the top of the refuse bed in the jig. No matter how the rate of feed may vary, either in tonnage or quality, the level top of this slate bed is maintained almost at a given point throughout the entire shift, making it impossible for clean coal to find its way through the orifice under plate (17) or for refuse to accumulate on the jigging sieve to a height sufficient to go over the overflow plate at (14). Uniform products of clean coal and clean refuse are thus secured.

Formerly the jig operator determined the conditions in the jigging bed by running his arm down into the coal in order to find the top of the bed of slate. Another method was to use a device, such as a bottle on the end of a broomstick, and, by practice, learn to determine this level by the ''feel'' as the bottle was lowered through the coal while the machine was in operation.

Frequently neither of these tests was faithfully practiced, and the regulation of the machine, insofar as the refuse removal was concerned, was controlled by the operator's observation of the two products coming from it. Whenever slate was noticed coming with the coal, more refuse was withdrawn. Whenever coal was noticed coming through with the slate, less refuse was withdrawn, and hence the adjustment of the machine was sometimes permitted to become entirely wrong before steps were taken to make it right.

Jigs with an Artificial Bed. This type is used only for fine coal, and the refuse is discharged through the perforations of the screen into the hutch. The difficulties of jigging increase with the fineness of the coal. The artificial bed is used to per-

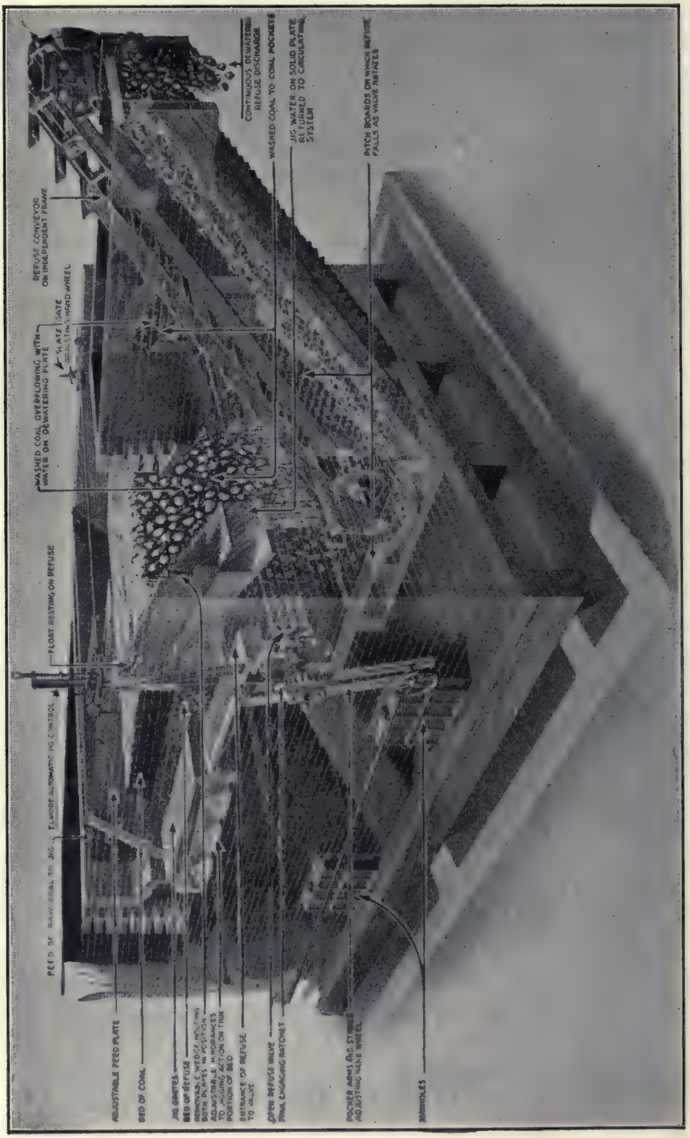


Fig. 91. "X" Ray Picture of Elmore Nut Coal Jig

mit the discharge of the refuse through the screen. A refuse discharge through a slotted opening or a gate would result in either too great a loss of good coal in the refuse or too much refuse would be carried over with the washed coal. Also, the small perforations in the screen required by the fineness of the materials would clog up easily and thereby nullify the pulsations.

In order to avoid all this trouble a screen is used with perforations somewhat larger than the largest size of material to be jigged. On top of this screen an artificial bed is laid, the material of which has a greater specific gravity than the refuse. The refuse finds its way through the interstices of the bed and drops into the hutch. The best material for an artificial bed has been found to be feldspar. For the first compartment feldspar between 1¼ and 2¼ in. in size, and for the second compartment pieces that have passed through a 1¼ in. and over ¾ in. round holes, is used. In some instances iron punchings or heavy slate have been used for a bed.

The discharge of the refuse is regulated in addition to the proper adjustment of the plunger stroke and speed, by the correct thickness of the bed and by using feldspar of a proper size. Both these values can only be determined by experiment. A deep bed consisting of small-size feldspar will give cleaner refuse than a shallow bed made up of larger pieces.

Feldspar is especially well adapted for the purpose of making an artificial bed on account of its specific gravity, which lies between 2.5 and 2.6. On account of its hardness it resists abrasion, and being sharp-cornered makes a safe bed, permitting the small particles of refuse to pass through but keeping back the larger pieces of good coal. Slate being soft, wears off its sharp corners too easily and must be renewed frequently. Iron is too heavy a material and kills or at least weakens the pulsation of the water.

Fine-coal jigs are often arranged in tandem, forming in reality a two-compartment jig. This arrangement exposes the material to the jigging action during a longer period, but restricts the capacity. Fine-coal jigs show the same variations in regard to design, operating mechanism and materials used in their construction as the coarse coal jigs. Fig. 92 shows a fine-coal jig,

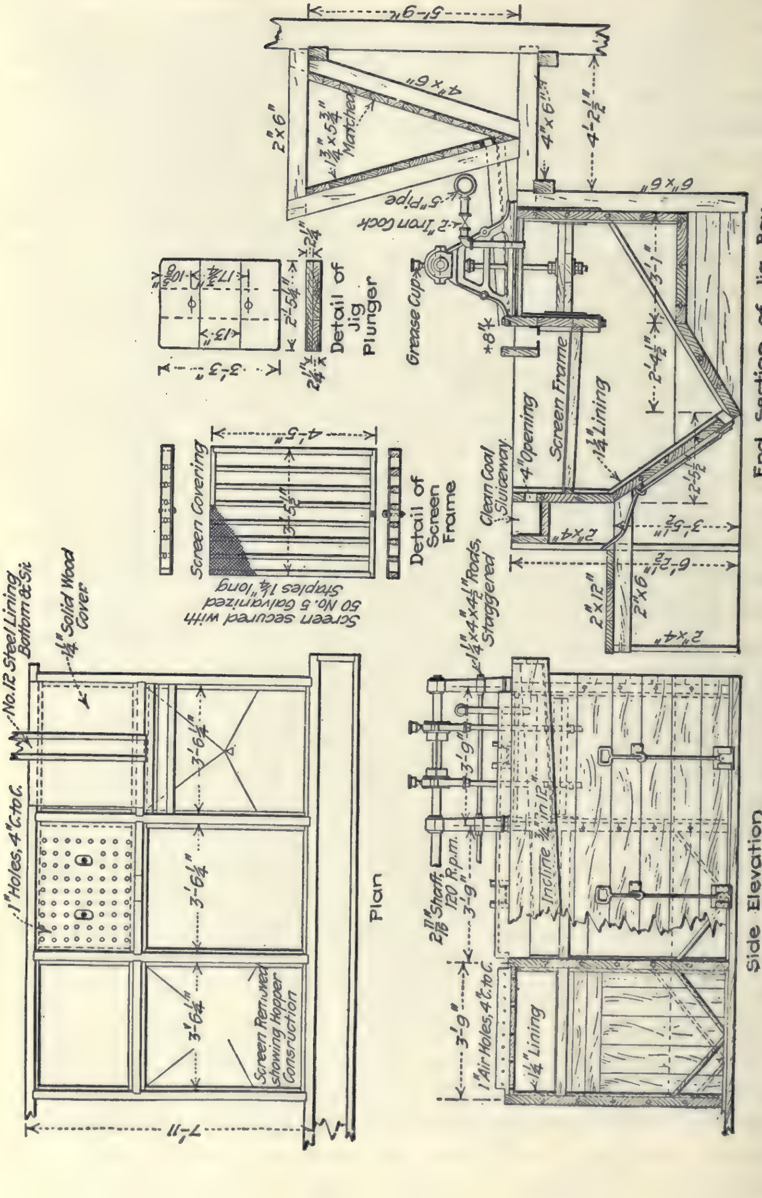


Fig. 92. Lührig Fine Coal Jig

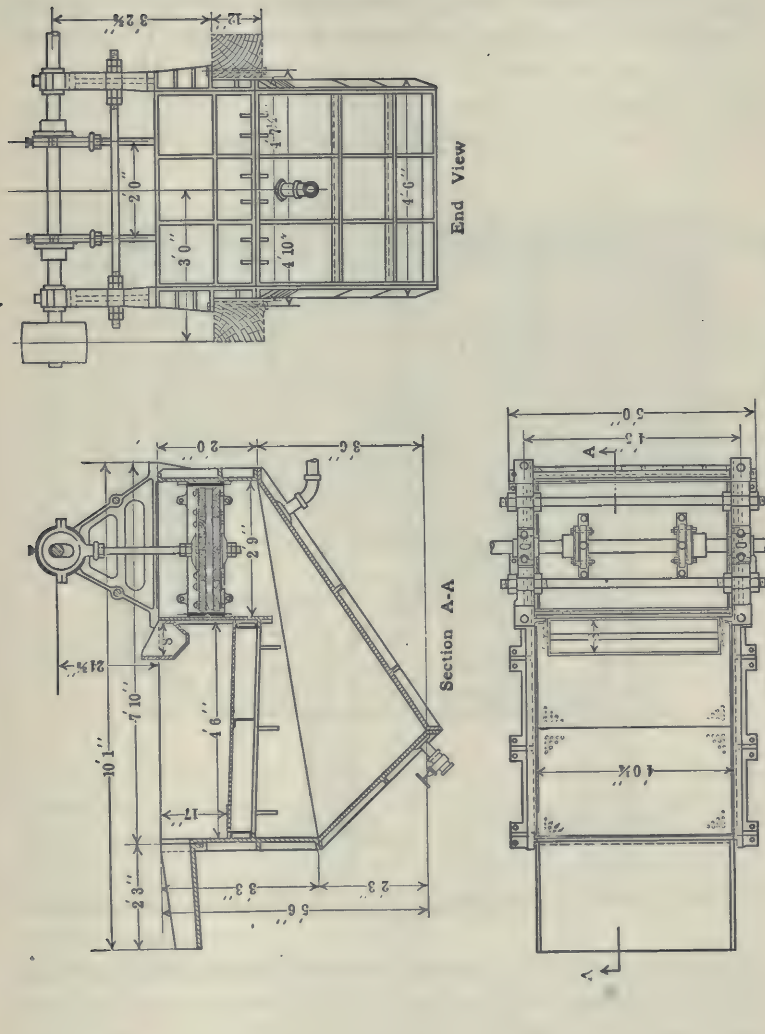


Fig. 93. Fine Coal Jig Built of Cast Iron Plates

with feldspar bed, built of timber, as used by the Link Belt Company.

Fig. 93 shows a feldspar jig built of cast-iron plates.

Jigs with Plunger Placed Underneath the Screen. This type of jig occupies less room for the same screen area. The effect of

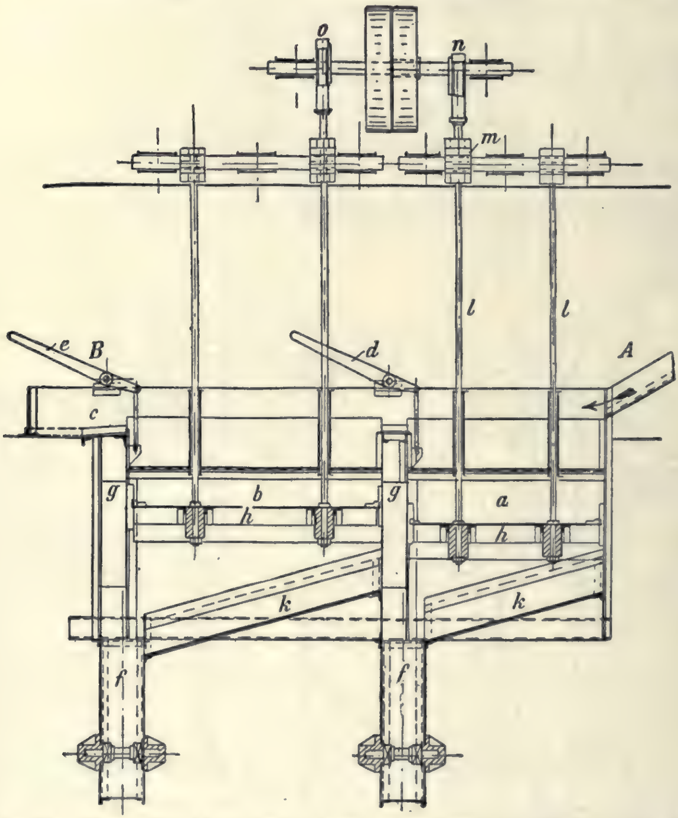


Fig. 94. Twin Two-Compartment Jig with Plungers Underneath the Screens

the water pulsation is uniform over the whole screen area and they require less power on account of the reduced friction of the water against the tank walls.

A double two-compartment jig is shown in Figs. 94 and 95. Each jig has two screen compartments "a" and "b." The coal

enters the first compartment "a" through the chute "A" and the clean coal overflows over the plate "c." A part of the refuse (the heaviest) is discharged at the end of the screen "a" through an adjustable gate "d" and the remaining portion leaves the jig at the end of the screen "b" through a similar gate "e." The refuse drops through the spouts "g" into the boots of the refuse elevators "f." Underneath each screen, a plunger suspended by two plunger rods "l," is located. These plungers have an inclined top surface, so that the refuse can

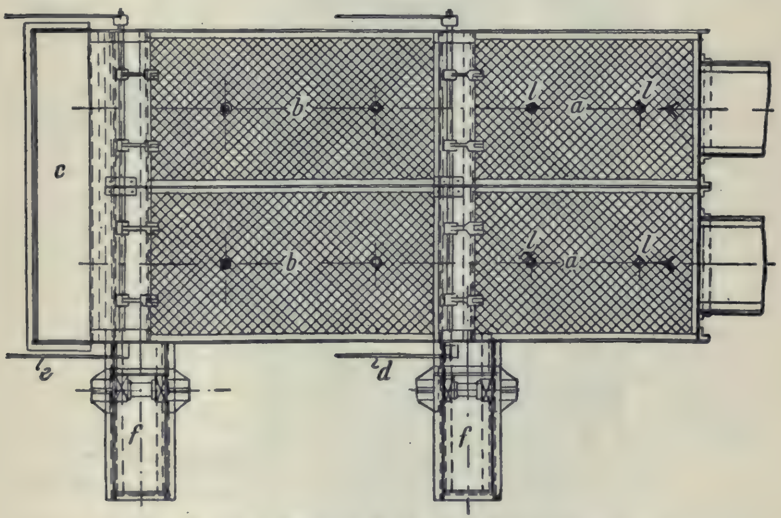


Fig. 95. Top View of Twin Two-Compartment Jig

slide off. This refuse drops into an inclined spout "k" and enters the elevator boots "f." The plungers of the screens "a" are connected by a walking beam "m" and eccentric drive "n" to one unit and the screens "b" are driven in unison by the eccentric "o." The eccentrics are set at 180 deg. so that but little power is required.

The Montgomery jig has a plunger underneath the screen, but the plunger is flat and has a number of flap valves to eliminate the suction on the down stroke of the plunger.

Raw coal enters behind the baffle plate "T" and passing under it, rises to the level of the overflow "Q" where it passes

out with water into the settling tank. Refuse is drawn at "I" into the refuse compartment "J" and down chutes "J_2" to the refuse elevator. Water returns from the settling tank enters the jig tank at "S" and on the upward stroke of the plunger or piston, enters through valves "O" into the space under the plunger. As the plunger moves down the valves "O" open and the space between plunger "N" and screen "P," is filled with

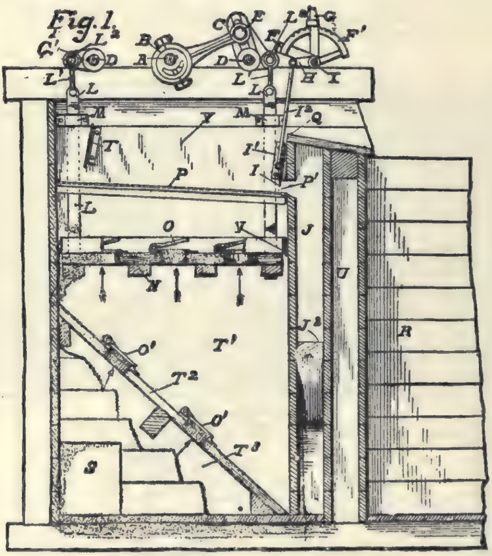


Fig. 96. Montgomery Jig

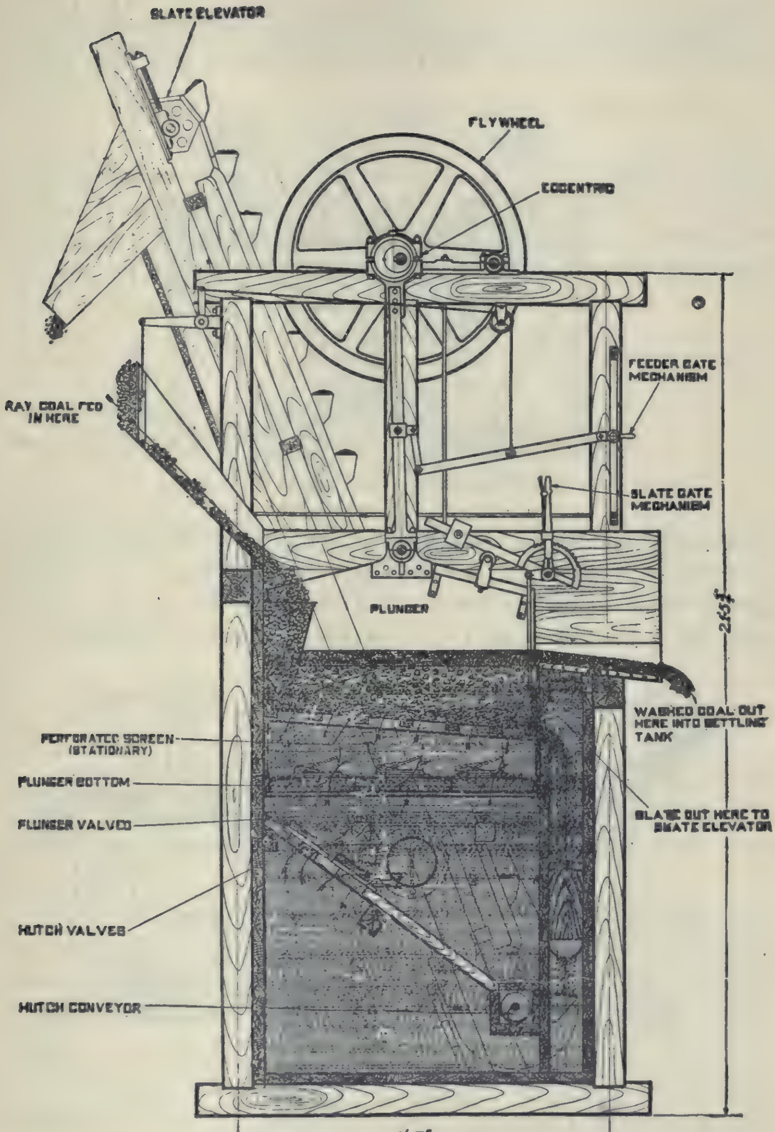
water. This is forced upward by the up stroke through screen and bed of coal.

Fig. 97 shows a Montgomery jig with a different driving mechanism and plunger construction.

Jigs with plungers on both sides of the screen compartment, are mostly built as two- or three- compartment jigs and were developed from the Faust jig which originated in the Joplin district.

Figs. 98 and 99 show the Faust jig as built for coal washing by the Link-Belt Co.

This jig has three compartments, the screen in each being slightly lower than that in the preceding one. Each of the



CROSS SECTION OF MONTGOMERY TYPE 'S' COAL JIG

Fig. 97

screens is supplied with a pulsating current of water by a pair of plungers, one on each side. The jig is intended for the smaller sizes of unsized coal from ¾ in. down. The finer refuse

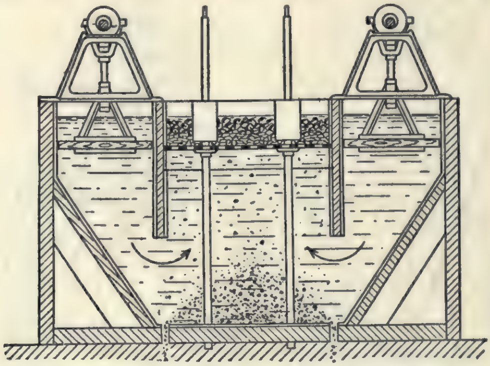


Fig. 98. Faust Jig. Cross Section

passes through the screens into the hutch, while the coarse refuse is removed through kettle valves, two in each screen. (A typical kettle valve design is shown in Fig. 100.) For ¾ in. unsized coal the plungers make 130 strokes per minute. The stroke in

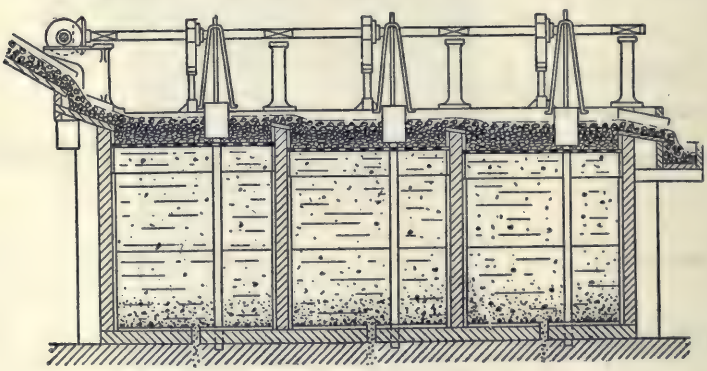


Fig. 99. Faust Jig. Longitudinal Section

the first compartment is 1 in. and in the second compartment ⅞ in.

Figs. 101 and 102 give the construction of a three-compartment, double-plunger jig built by the Roberts & Schaefer Co.

This jig has kettle valves in the first two compartments and a rotary valve in the third compartment for the removal of the refuse.

Figs. 103–104 show a two-compartment, double-plunger jig built by the American Coal Washer Co.

Both compartments have kettle valves for the removal of the refuse. Each plunger has 8 poppet valves, which open on the up-stroke, for the purpose of killing the suction under the screens. The driving mechanism is located below the jigs, mak-

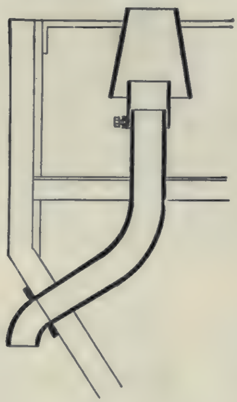


Fig. 100. Typical Design of a Kettle Valve

ing these machines accessible from all sides. The jigs are built of cast-iron plates, securely bolted together and stiffened with heavy ribs. This makes a durable and extremely rigid construction.

Jigs with the Plunger Between the Compartments. This type of jig is not extensively used. To get the proper pulsation a large plunger would be required, since under ordinary conditions the plunger area is about one half of the screen area. For this reason this type of jig is mostly employed for treating fine coal using a feldspar bed on the screen. Fine coal requires a less intensity of pulsation than the coarser sizes and a relatively smaller plunger area will be sufficient.

Figs. 105 and 106 show a two-compartment double jig with plungers between the screen compartments.

The plungers move in a vertical direction and separate plun-

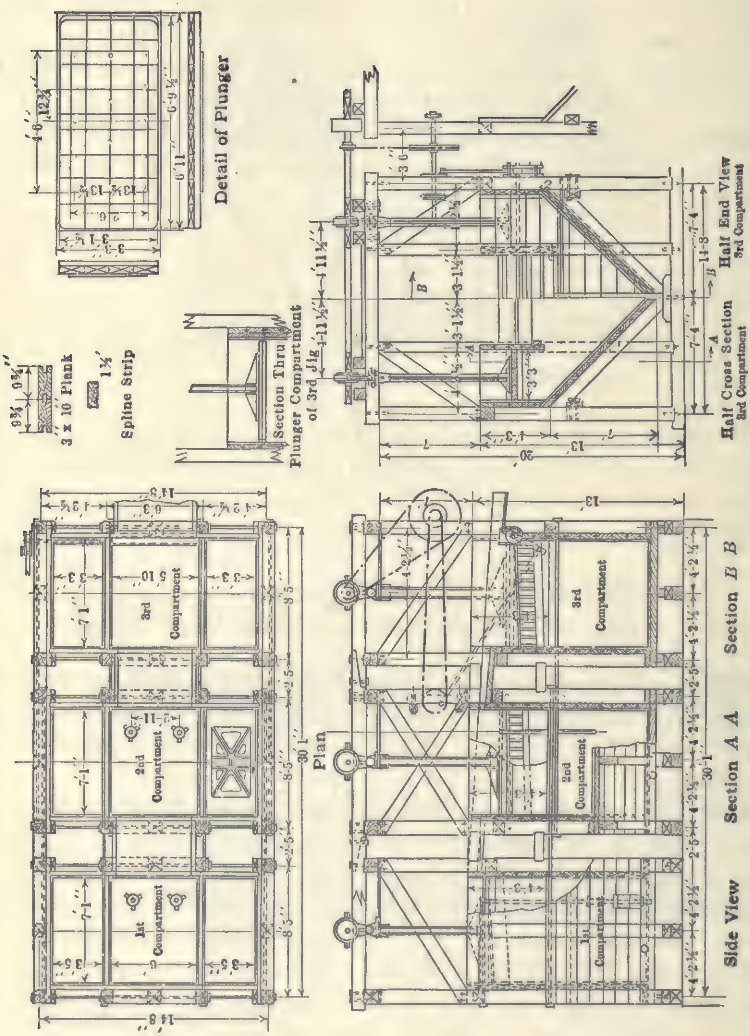


Fig. 101

Fig. 102

Three Compartment Double Plunger Jig

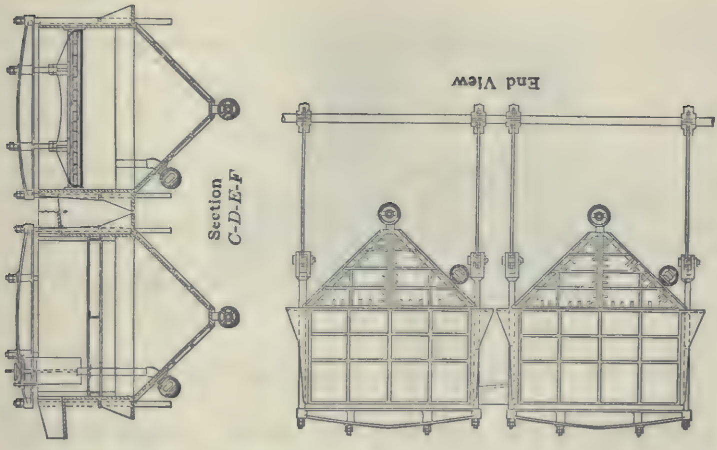
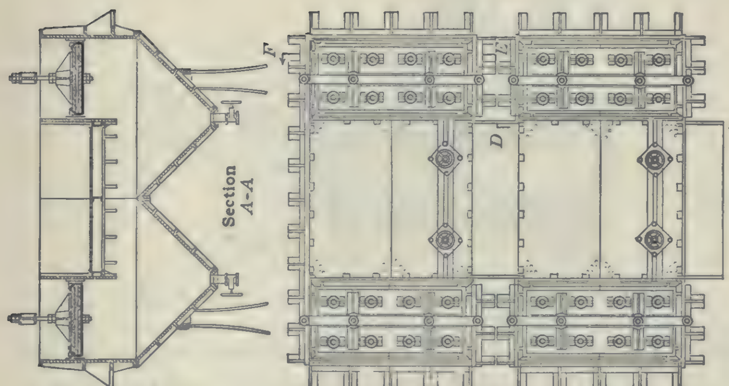


Fig. 104



Plan

Fig. 103

Two-Compartment Double Plunger Jig

gers are used for the first and the second compartment. This permits giving the plunger for the second compartment a different stroke from that for the first compartment. This is neces-

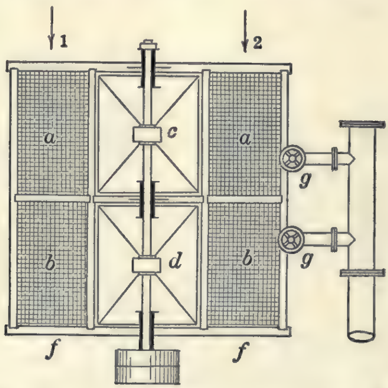


Fig. 105. Two-Compartment Double Jig. Top View

sary, since the material treated in the second compartment is quite different from that coming into the first compartment, having lost most of its heavy impurities.

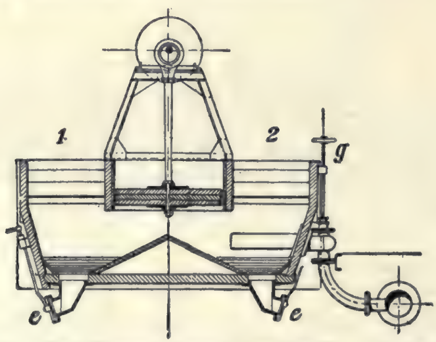
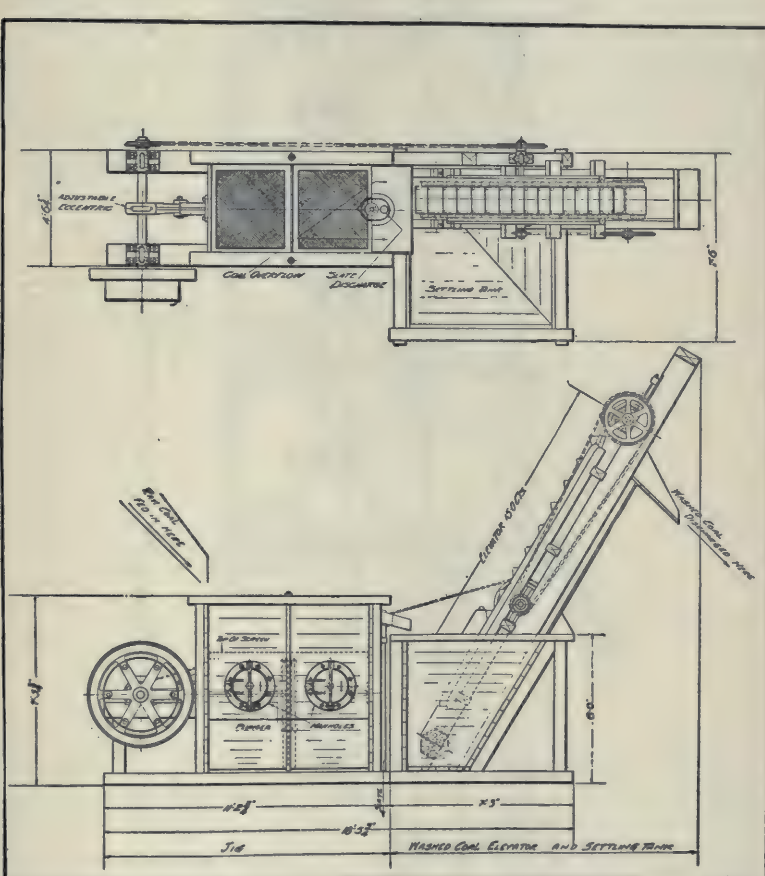


Fig. 106. Two-Compartment Double Jig. Cross Section

Figs. 107 and 108 show a two-compartment single jig, in which the plunger is located below the screens, and moves in a horizontal direction.

This arrangement gives the same pulsation to both compartments, which is theoretically wrong. It makes a decidedly com-

pact construction with all the moving parts out of the way of the operator. A similar arrangement was used in the early days of ore dressing. The three compartment double jig of Kasselowsky shown in Figs. 109 and 110 has a vertical plunger under-



Figs. 107 and 108. Two Compartment Jig with Plunger Below the Screens

neath each compartment, serving two screens. In this construction the stroke of each plunger can be adjusted according to the characteristics of the material on each screen. This type of jig has been later on adopted by Parsons and Fischer.

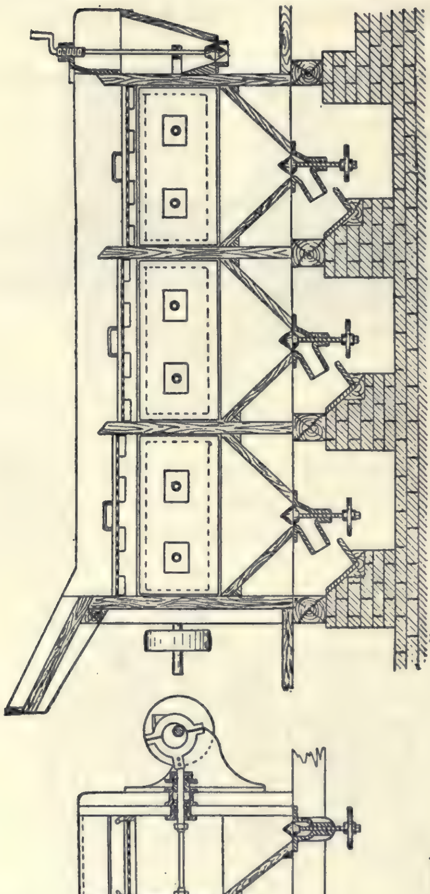


Fig. 110
Longitudinal Section

Kasselowsky Three-Compartment Double Jig

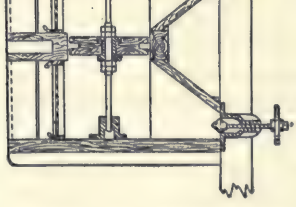


Fig. 109
Cross Section

Jigs Without Plungers. Jigs without plungers have been introduced by Baum, who also originated the slogan *"First Washing, then Classifying."*

Figs. 111, 112 and 113 show the construction of a two-compartment jig for treating unsized coal.

This machine makes three products, and the pulsation of the water is produced by compressed air of 1½ to 2 lb. pressure per square inch. This reduces the moving parts to simple air valves located above the rear or water compartment of the jig. The construction of the air valve is shown in Fig. 111. Here *P* is

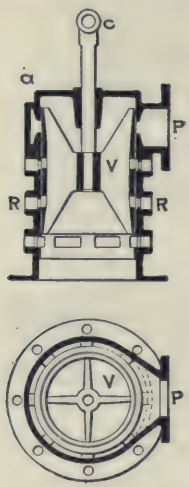


Fig. 111. Air Valve for Baum Jig

the inlet port for the compressed air. The piston valve *V* is moved up and down by the eccentric drive *c*. In the highest position of the valve, as shown in the illustration, the air in the water compartment *b* can escape through the exhaust ports *R*. In the lowest position of the valve the compressed air enters through the port *P* and expands at first to some extent on account of the increase of area; but soon the pressure in the valve will be equal to the pressure in the supply pipe. The motion of the water is reversed on the exhaust stroke of the valve. The amount of air can be regulated by the length of stroke, the intensity of the pulsation by the pressure of the air, and the fre-

quency of the pulsations by the speed of the eccentric shaft.

The jig shown in Figs. 112 and 113 has two screens, *d* and *e*, both of which are slightly inclined against the direction of the flow of materials. The first and larger screen has three and the second or smaller one two air valves. The heavy slate is discharged immediately at the feed end of the jig through the slate gate *f* and falls through the chute *g* into the elevator *h*. This peculiar method of slate discharge prevents the

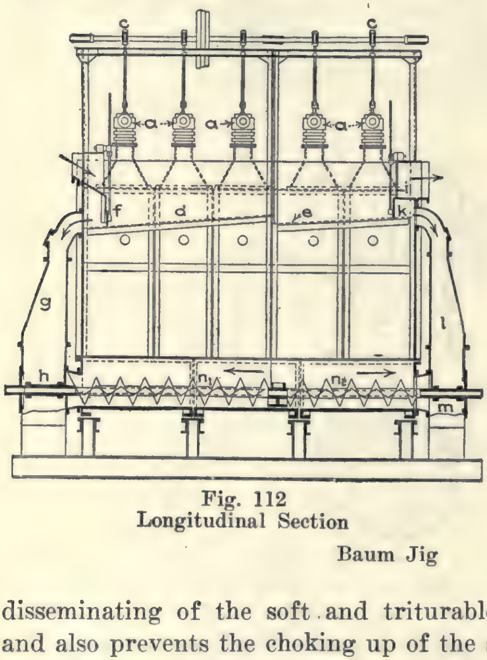


Fig. 112
Longitudinal Section

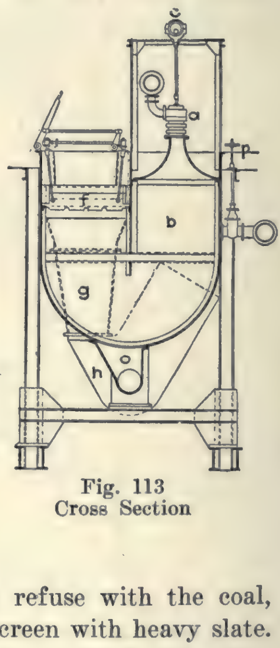


Fig. 113
Cross Section

Baum Jig

disseminating of the soft and triturable refuse with the coal, and also prevents the choking up of the screen with heavy slate. On the second screen *e* the clean coal is separated and overflows at *i*. Light refuse or the middle product, according to the character of the coal, is discharged at *k* and falls through the chute *l* into the elevator pit *m*. The sludge and fine refuse which passes through the perforation of the screens is conveyed by means of a right- and left-hand conveyor *n1* and *n2* to the elevator pits *h* and *m*. The water is regulated at *p*.

No fundamental difference exists between the method of operation of the jig described above and other machines. The pe-

culiarity of the use of compressed air can be partly explained by the large size in which the jigs are built. But plunger-jigs also are built in equally large sizes for the treatment of unsized coal and are quite successful.

Fig. 114 shows a single-compartment "Baum" jig with double slate gate.

The above described Baum jigs have the great advantage, that the pulsation of the water can be regulated by the intensity of the air pressure, without interrupting the operation of the jigs.

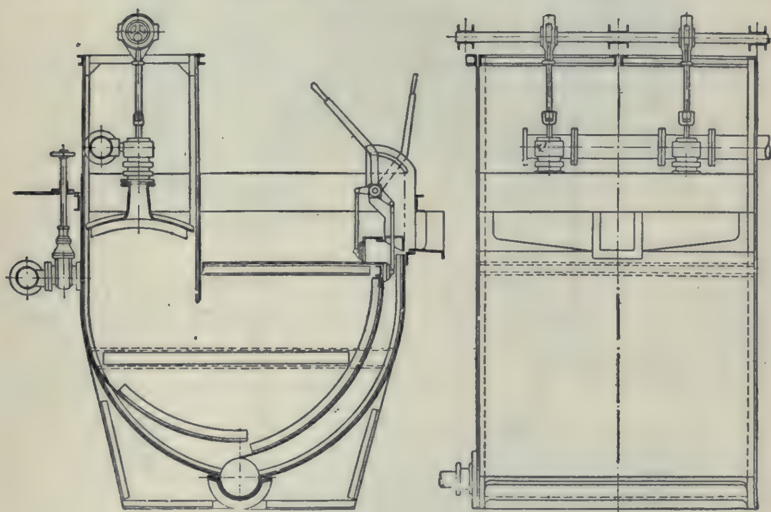


Fig. 114. Single Compartment Baum Jig

Reciprocating Jigs or Jigs with Movable Screen. The construction of this type of jig does not show so many varieties as that of the fixed-screen type. Jigs of this type are used for unsized coal and make but two products. The only difference in the construction of the jigs is found in the arrangement of the slate gate and the methods used to diminish the suction on the upstroke. Fig. 115 shows the Stewart jig in connection with the jig tank. Fig. 116 shows the side view and Fig. 117 the top view, or rather bird's-eye view, of the jig basket. Fig. 118 shows the "American" jig. This machine is provided with adjustable wearing plates on the sides, securing a water-tight joint

between the jig basket and the tank. The swinging slate gate, operated by the reciprocating motion of the jig basket, is opened at intervals but always to its fullest extent, in order to prevent the accumulation and jamming of large pieces of refuse in front of the gate. The interval between successive openings of the

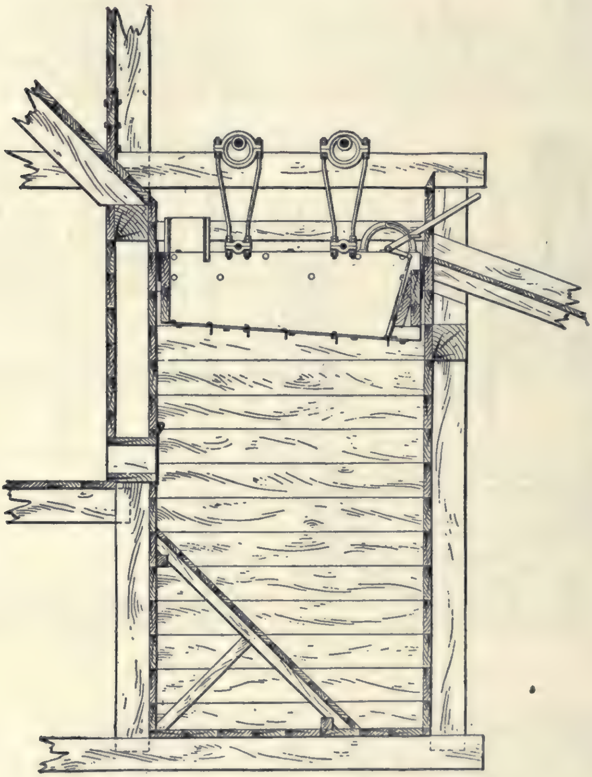


Fig. 115. Stewart Jig with Jig Tank

gate can be changed at the discretion of the operator. To obtain a closer regulation of the slate discharge, the operator can easily regulate the length of time the slate gate remains open. This is accomplished by means of a sliding cam which changes the time that the slate gate remains open by infinitesimal increments.

The Pittsburg Jig is shown in Fig. 120.

This Jig is of the well-known reciprocating type, 4 ft. wide and 7 ft. long, inside dimensions, with the new feature of a secondary bottom fitted with flap valves so arranged as to admit

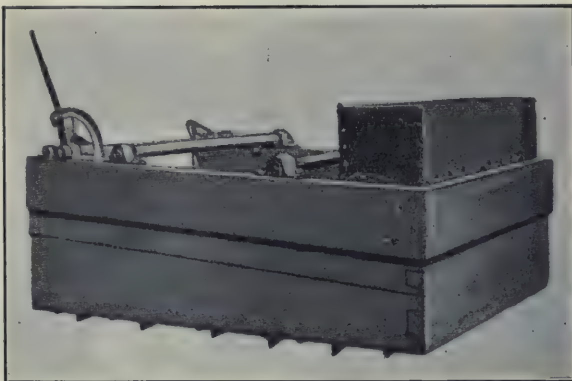


Fig. 116. Side View of Stewart Jig Box

of a free upflow of water on the downward stroke and closing and holding the water on the upstroke of the jig, as will be readily seen by the accompanying cut of the jig; the bottom of the jig slopes down toward the front.

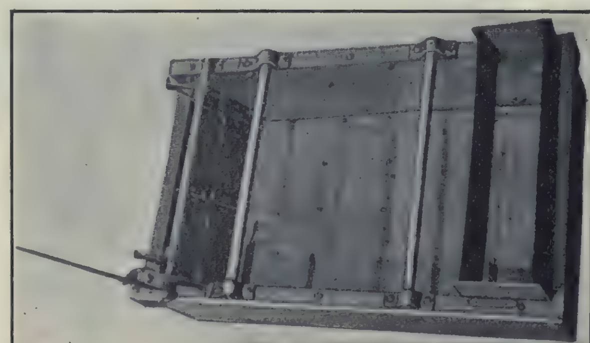


Fig. 117. Top View of Stewart Jig

The driving mechanism of these jigs is especially interesting. These jigs travel twice as fast on the downstroke as they do on the upstroke. This result is obtained by the use of a slotted

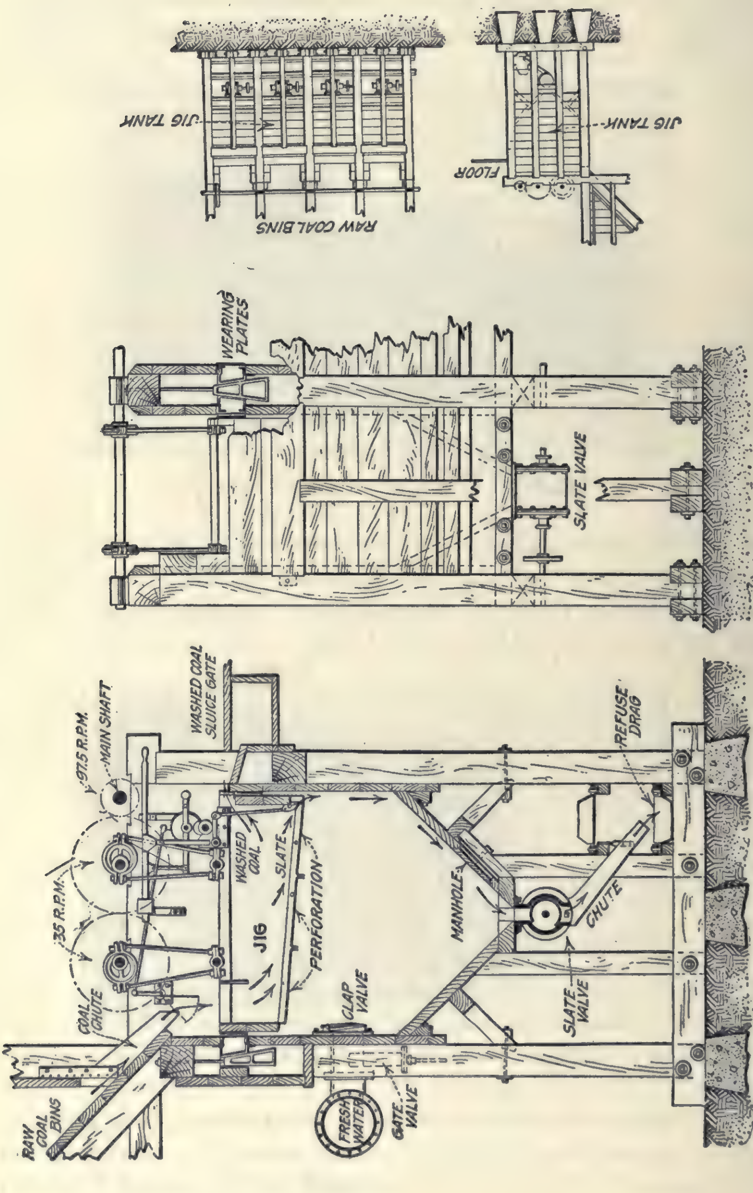


Fig. 118. "American" Jig with Tank

lever and crank fitted with hardened steel roller and brass bushings, so arranged that on two-thirds of the revolution of the driving gear wheels, the slotted lever is pulling the jig up and on the remaining one-third of the revolution, the slotted lever is pushing the jig down, accomplishing the desired results. All this mechanism is adjustable as to length of stroke and differential between up and down strokes.

The tanks in which the jigs reciprocate are equipped with a flap valve which allows the water to enter, but closes as soon

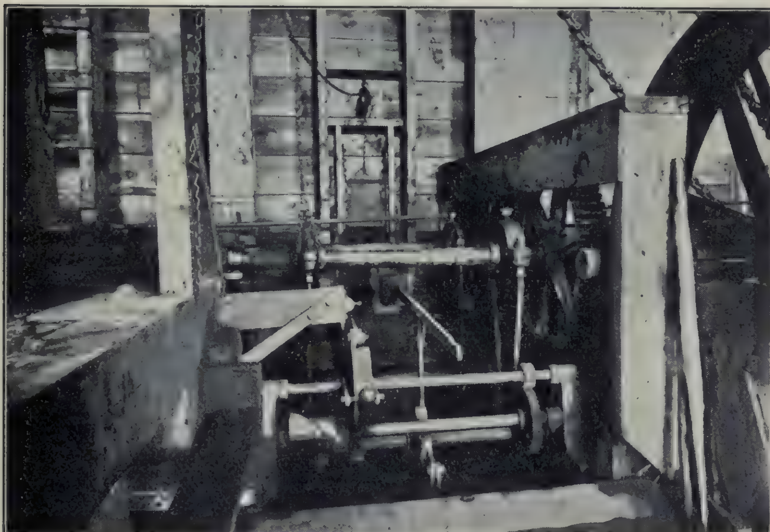


Fig. 119. American Jig Showing Slate Gate Operating Mechanism

as the jig begins its downstroke. As the jig begins its downward motion, the water is forced up through the valves, and, accordingly, up through the screen bottom, lifting off the material from the screen. On the beginning of the upward stroke the flap valves in the secondary bottom close, permitting the materials in the jig to settle and stratify in a practically quiet body of water. The refuse settles to the bottom and gradually works forward with each stroke to the slate gate. The coal flows over with the water on to a very finely perforated screen, from which it is conveyed into a washed coal bin, the water draining through

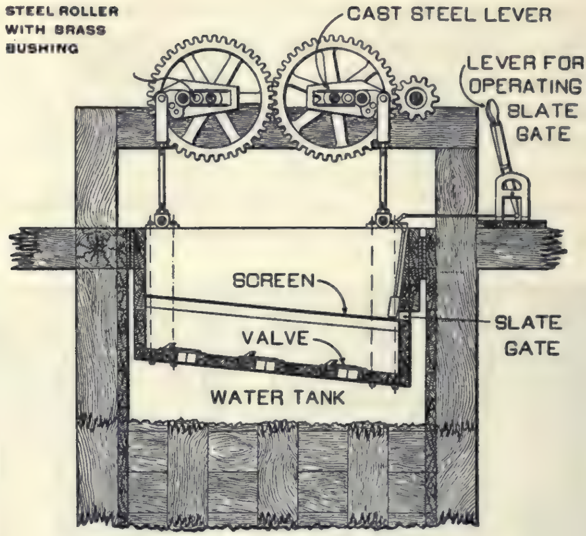


Fig. 120. Pittsburg Jig

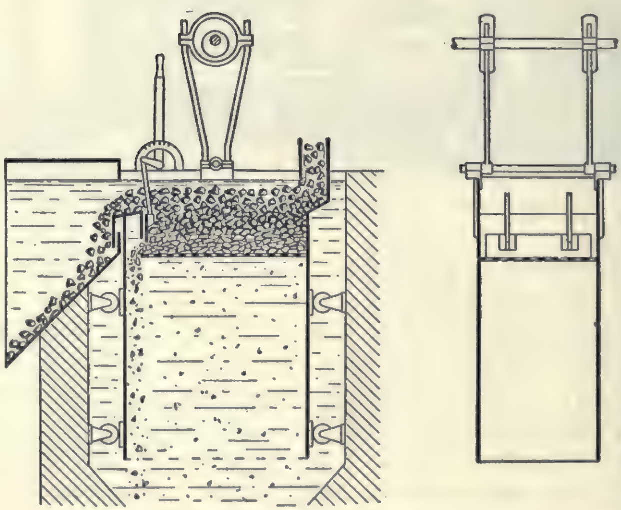


Fig. 121. Shannon Jig

into a supply tank which adjoins the jig, and is connected to it by the above mentioned flap gate, thereby enabling the use of the same water a number of times without the necessity of pumping, each jig handling its water automatically.

The Shannon Jig, shown in Fig. 121[1] does not attempt to force the water through the coal in the pan by making it fit the pan compartment snugly, but obtains a similar effect by prolonging the sides of the pan downwards below the screen and using comparatively rapid strokes. The pan is held free from the walls of the pan compartment by means of rollers. Another peculiarity of the Shannon jig is that the washed coal and pan compartments are connected at the top so that water is free to move back and forth between them. This greatly reduces the quantity of water which must be pumped to keep the jig going.

The jig is 4 ft. wide by 6 ft. long, inside dimensions, and is rated to treat on an average 47 tons of raw coal per hour. The number of strokes varies from 72 to 90 per minute, while the length of the stroke is from 3 to 3½ in.

[1] "Coal Washing in Illinois," by F. C. Lincoln. Bulletin No. 69, Engineering Experiment Station, University of Illinois.

CHAPTER XX

GENERAL DATA ON JIGS

Owing to the great variety in the construction and arrangement of jigs, it is hardly possible to give authentic figures in regard to the work performed. This furthermore becomes more complicated, as the work and the output of a jig depend not only on the proper selection of certain dimensions such as length and width of jig screens, proportion between plunger and screen area, height of overflow above screen, and the size of perforations in the screen, but also on the proper regulation of the plunger stroke, speed of eccentric shaft, size of materials, thickness of bed, water supply and many other considerations.

The details of construction and the methods for securing a proper adjustment were developed by each builder of jigs independently and according to his own ideas. For these reasons we have a multiplicity of designs and data on operation which, however, give similar final results. In any case, however, the tabulation of the most important data for each type of jig (see table 32) requires some explanation.

The methods used will change the relation between the different factors independently of the capacity, which naturally influences the size of the jig. If coal is sized before washing, a series of small jigs will be required; whereas if unsized coal is to be treated, quite frequently one large coarse-coal jig will suffice. This will explain the considerable difference in the dimensions and the capacity of the jigs. The character and the size of coal on the one hand and the type of the jig on the other strongly influence the length of the plunger stroke. The number of strokes per minute must be increased in inverse proportion, and the length of the stroke in direct proportion to the size of the coal. That is, coarse coal requires a slower and longer stroke than fine coal, for which a short, quick pulsation is more advisable. The size of the perforation in the screen must be

smaller than the smallest size of the coal. The big difference in the power consumption can be explained by the different sizes of the jigs.

Jigs for unsized coal are mainly built for great capacity. In some cases the whole amount of raw-coal screenings is put over one jig only, and I know of some machines treating 150 tons of raw coal per hour. The perforations in the screen are larger than in the screens of coarse-coal jigs, because a heavier pulsation is required to loosen up the unsized coal. This, however, will make the size of perforation in the screen larger than the size of the smallest particles of the material to be treated, and the refuse collecting on the screen must prevent the downward passage of the fine coal.

In addition to the foregoing considerations it is of great importance to determine the correct thickness of the artificial bed and the proper size of the material to be employed. The data shown in the table can be used only as a guide. Different coals will require different beds.

TABLE OF THE MOST IMPORTANT JIG DATA

	Coarse Coal Jigs	Unsized Coal Jigs	Fine Coal Jigs
Width of jig screen	24 in. to 6 ft. 6 in.	30 in. to 6 ft. 6 in.	20 in. to 7 ft. 3 in.
Length of jig screen	3 ft. 3 in. to 16 ft.	6 ft. 6 in. to 19 ft. 6 in.	6 ft. 6 in. to 21 ft. 4 in.
Capacity per hour in tons	5 to 150	30 to 150	5 to 70
Capacity per sq. ft. of screen area in tons	0.4 to 1.0	0.8 to 1.5	0.3 to 0.5
Number of strokes per minute	20 to 100	35 to 110	100 to 200
Length of stroke in inches	1½ to 16	1¼ to 6	⅜ to 2
Proportion of area of plunger to screen area	0.7: 1 to 1: 3	1: 2 to 1: 2.5	1: 1 to 1: 1.5
Size of perforations in screen in inches	⅛ to ½ in.	5/32 to ¾	⅜ to ½
Size of bed material in inches...	....	....	9/16 to 1½
Thickness of bed in inches	....	....	2 to 4
Horsepower required	1 to 6	3 to 10	1 to 5

TABLE 32

The Control of the Washing Process

Upon the character and nature of the raw coal depends the selection of the proper type of jig, as well as the methods to be followed in washing the coal, but the efficiency of these methods depends much upon the control of the washing process. J. T. Drakeley, in his paper, "Coal Washing; A Scientific Study," has ably analyzed the different methods of control and the effects that changes in operation of the jigs have upon the output.

Considerable more attention ought to be paid to the control of coal washeries. Undoubtedly at many washeries regular float and sink tests are not made, and it is only upon the interpretation of the results of such tests that it is possible to base arguments in favor of any variation in the working of the washers. That these tests should be made is recognized generally, especially where jig-washers are used, as their control introduces many factors. With trough and inverted-cone washers the freedom of control is more restricted.

The control which is exercised over jig washeries usually consists in regulating: (1) the supply of raw coal, (2) the supply of water, (3) the stroke and speed of the eccentric action, and (4) the outflow of the refuse.

(1) **Supply of Raw Coal.** If the raw coal is fed too rapidly onto the wet screen, no opportunity is given for any considerable separation to occur before the material is compelled to leave the jig. This means that the percentage of refuse (sink particles) in the washed coal is high, while the loss of coal in the refuse is also high. On the other hand, if the supply of raw coal should be too slow, only the best material is carried away as washed coal. The usual openings of the refuse valves release a refuse which necessarily contains a large percentage of good coal. The above holds good only if the common type of hand operated refuse gates are used. With kettle valves or the "Elmore" automatic refuse valves, no such loss of good coal can occur.

(2) **Supply of Water.** If water is pumped into the jig too rapidly, it is capable of flushing away in the washed coal an unduly large quantity of refuse; but, as only the heavier parts of the material can sink through the rapidly moving stream of water to the screen, the refuse contains little good coal.

The trouble, which is introduced by admitting too little water, is, that at each up stroke of the plunger there is a strong suction in the jig tank. This tends to arrange the lightest particles near the screen. In consequence, the washed coal is largely composed of refuse, and good coal forms a considerable portion of the refuse.

(3) **Stroke and Speed of the Eccentric Action.**—(a) *Long and Rapid Stroke.* The more violently the downward stroke of the plunger is made, the greater is the distance that each particle is separated from its neighbor. A better opportunity is, therefore, offered for the materials to settle in accordance with their respective specific gravities. A rapid upward pulsation in the jig necessitates, however, a rapid discharge of water from the jig, and it has been observed that too strong a stream of water does not result in effective separation.

With a long and rapid down stroke, it will be essential for the machinery to provide for a somewhat slower up stroke of the plunger; otherwise, the admission of water, to prevent a suction at the screen must be large, and, in consequence, the ill effect of a strong current of water is aggravated.

(b) *Long and Moderately Slow Stroke.* With a long slow stroke, especially where provision is made for a slower up stroke of the plunger, the best conditions are obtained for washing nut coal. The long but moderately slow down stroke of the plunger produces just sufficient agitation for the materials to settle freely during the slower up stroke. As water is admitted below the screen, the settling occurs in an almost still liquid.

For fine raw coal in a feldspar-washer even a long and moderately slow stroke is not essential, as the agitation is unnecessarily great, and the rate at which the coal is washed is limited.

Where fine coal is being washed with larger sizes, a long and somewhat slow stroke is essential. Even then, the rapidity with which the stroke must be made to agitate the larger sizes causes such a rush of water from the box that fine dirt is carried away with the coal.

Hence, where unsized coal is washed and subsequently classified, the fine washed coal is improved, as a rule, by a second washing. Obviously, if the stroke is too slow, insufficient freedom is produced in the washing-box, and the plant delivers from

the washed coal and refuse outlets products differing little from the original raw coal.

(c) *Short and Rapid Stroke.* A short stroke, even though it is rapid, does not produce sufficient freedom among the particles of nut-coal to secure good separation. On the other hand, a short and fairly rapid stroke is admirable for the fine coal. The short stroke brings about sufficient freedom for the particles to settle easily during the up stroke of the plunger. It is, of course, essential that water shall be admitted to prevent suction at the wet screen; otherwise, not only do the materials settle in the reverse order, but a large quantity of fine stuff is sucked through the feldspar bed, to be lost as refuse.

(d) *Short and Slow Stroke.* A short and slow stroke would, probably, produce no movement in a washing-bed composed of large particles, and even with fine coal it would be unsatisfactory, as insufficient separation would be effected.

(4) **Refuse Discharge.** The refuse discharge must be so regulated that it corresponds with the rate of accumulation of the impurities. If it is too slow, the impurities pass out in the washed coal, while the refuse is confined to the dense particles of impurities; whereas, if the outlet is opened too frequently, some of the coal escapes with the impurities, and only an extremely high-grade washed coal is delivered. A tabulated statement of the above facts concerning jig-washers is given in Table 33.

With such devices as the trough and the inverted-cone washers, there is only the possibility of varying the supply of raw coal and water, and of regulating the removal of the refuse. If the supply of raw coal or water is too great, to either the trough or inverted-cone washer, the washed coal contains a large quantity of impurities, whereas the refuse is confined to the denser impurities. A similar state of affairs is brought about by releasing too little refuse. On the contrary, if the supply of raw coal or water is too small, the usual openings of the refuse-valves discharge a refuse which contains a high percentage of coal. The washed coal then is of the highest grade. By releasing the refuse too rapidly the same result is produced.

Effect and Cause in Jig-Washing

Description	High percentage of coal in refuse	Low percentage of coal in refuse
High percentage of impurities in washed coal	(*a*) Feed of raw coal too rapid. (*b*) Strong "suction" at wet screen due to: (i.) Small admission of water. (ii.) Long and rapid stroke with insufficient supply of water. (*c*) Stroke too slow (long or short). (*d*) Stroke too short and rapid (nut-washer).	(*a*) Water-supply too great. (*b*) Stroke too long and rapid, with good water-supply to prevent suction. (*c*) Too small a quantity of refuse released.
Low percentage of impurities in washed coal	(*a*) Feed of raw coal insufficient. (*b*) Too large a quantity of refuse released.	All details of washer suitably adjusted.

Table 33

CHAPTER XXI

CONSTRUCTION OF JIGS

Jigs built of timber are light in weight and cheap in first cost. The jig boxes can be repaired and even totally rebuilt at the washery. But they are hard to keep tight and not very durable. The best wood for the construction of jig boxes and tanks is long-leaf yellow pine of heart specification. In some instances creosoted timber has been used. Timber construction is especially advisable if the wash water becomes acidulous.

Jigs built of steel plates are comparatively light but expensive. They must be stiffened with angle irons and braces to keep the side plates from breathing.

Cast-iron jigs appear to have the preference at present. They are rather heavy but stiff and solid. They are not affected by acidulated water and always represent the value of scrap iron, if for any reason it becomes necessary to change the type of jigs.

Reinforced concrete has been used in several instances in the construction of jig tanks. This material, however, has the great disadvantage that it is affected by acidulated water to a highly disastrous degree. The solid, heavy construction of reinforced-concrete tanks prevents also any changes or alterations. A reinforced-concrete jig tank must remain the way it has been put up in the first place, or it must be entirely rejected if changes become necessary.

The proper selection of the material of which jigs should be built depends on cost of construction, cost of upkeep, nature of the wash water and the design of the supporting structures.

Side or end plungers actuated by eccentrics give, under normal conditions, perfect satisfaction. If the coal is difficult to wash a differential motion drive for the plungers would be advisable. In cramped quarters considerable space can be saved by the use of plungers placed below the screens. For extremely large jigs compressed air can be used to advantage.

The discharge of washed coal is similar in all jigs. It consists of a simple overflow dam or weir. The discharge of refuse, however, shows many variations and has been elaborated previously. For jigs treating unsized or the larger sizes of coarse coal plain gates can be used. This type is almost universally employed on reciprocating jigs. The gates can be either of the slide or swing type. The swing gates offer some advantages over the slide gates as they permit the removal of the heaviest pieces of refuse without disturbing the bed.

The kettle or pot valves are to be recommended for coarse-coal jigs. They permit a close regulation of the slate bed and have the further advantage that they prevent an accidental loss of the slate bed, caused by inattention of the operator. The kettle valve being open on top permits an inspection of the refuse. The double slate gate is nothing more nor less than a developed kettle valve extending over the whole width of the jig. It is at present the best design known, as it combines the good points of the kettle valve with those of a slide gate.

Revolving slate valves are only to be used for fine-coal jigs, as the heavy refuse accumulating in coarse-coal jigs is apt to choke up this type of valve. For the removal of the fine refuse passing through the perforations of the screens, a common molasses gate is the simplest and best device. Other types of mechanically operated valves for the discharge of hutch work have been designed, but they all appear to be entirely too complicated.

To facilitate the operation and supervision of the washing process it is desirable to locate all the jigs, including the rewash machines, on a common platform. This permits the consolidation of a number of jigs in a battery thereby saving space and cost of installation. The rule is to provide each compartment of a jig with one separate plunger. If one plunger should be used for two compartments, there would be great danger that the jig work of these compartments would be uneven and unsatisfactory. The second compartment is treating quite different material from the first, and as explained previously length and frequency of plunger stroke must be adapted to the material to be treated. So it can be clearly seen that it will be absolutely wrong to treat two different materials with the same kind of pulsation. The

jigs should be placed in such position that they will be accessible from all sides; and to facilitate the inspection of the work performed they ought to be placed somewhat higher than the operating platform.

CHAPTER XXII

CONCENTRATING TABLES

For the washing of coal too fine to be treated successfully on jigs, concentrating tables are coming into use. Such tables have been employed for many years in ore-dressing plants, and the principle applied for ore concentration can also be used for coal washing. The specific gravity of the material and the size of the grains are two of the most important considerations. Specific gravity comes first and size of grains is second in importance.

Many types of concentrators for fine material have been developed, but among them the machines with the separating surface in motion and having a continuous feed and discharge are the most important. The machines belonging to this group utilize mechanical agitation to separate the grains into layers. The pulp, in its passage across the table deck, stratifies, in accordance with the specific gravity of the different particles, the heaviest seeking the lower strata between the riffles, while the coal or lighter particles remain on top, to be washed off the side of the deck by the cross flow of wash water, the heavier, or high-ash grains, being guided by the riffles and advanced to the end of the deck by the head motion and discharged as refuse. This separation is visible at all times while the table is in operation, and susceptible of exact adjustment and under easy control of the operator.

Concentrating tables for coal use riffles on the table deck. These riffles are produced by tacking cleats on the table surface. The arrangement of the riffles forms at present the main difference between the different tables. Other differences can be found in the manner in which the shaking motion of the deck is produced. In any case the backward motion should be faster than the forward motion. The movement is either parallel to the direction of the riffles or the riffles are placed at an angle to the direction of the table motion. In some cases this angularity of

the riffles is only carried on for a short distance in the middle of the deck. Whatever the direction of the riffles, the table motion moves the material toward the refuse side of the machine. The refuse collected on the bottom of the riffles is carried forward faster than the clean coal forming the upper strata of the bed. The wash water, however, washes the clean coal down the slope of the table much faster than the deeper stratified refuse.

There are now employed for coal washing five distinct types of concentrating tables, all of them adopted from the same types used in ore dressing.

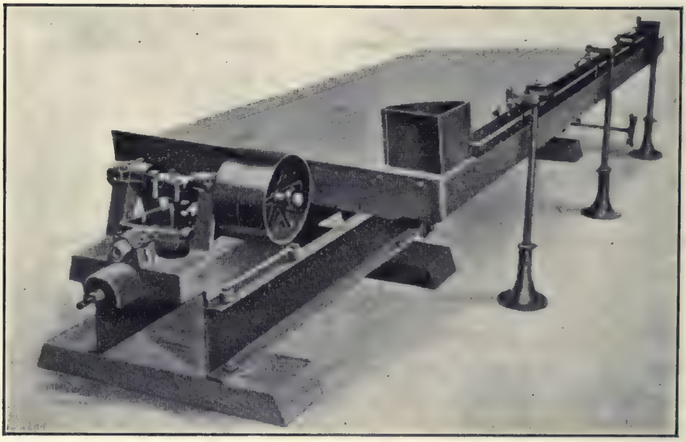


Fig. 122. Massco Coal Table

The Massco Coal Washing Table, illustrated in Fig. 122 is, strictly speaking, a Wilfley table used for coal washing.

The Massco table consists essentially of a linoleum-covered riffled deck about 7 ft. wide by 16 ft. long, transversely inclined and reciprocated endwise by a head motion mechanism. The crushed coal, previously mixed with about three times its quantity of water, is fed onto this deck through a feed-box at the upper corner. The power required for each table is about ¾ h.p., and the capacity with ¼ in. coal has been found to be from six to eight tons per hour. The table should run at about 220 r.p.m. The deck ought to have a side inclination of about 3 in. from the feed to the coal discharge side. Soon after the

coal has been fed onto the table a line of separation between the washed coal and waste will become apparent in a generally diagonal direction from the feed-box toward the waste discharge corner. By varying the inclination of the deck the location of this line will change. The nearer horizontal the deck, the higher up this line will terminate, and vice versa; but the proper location of this line is such that it shall terminate at the lower waste discharge corner.

There is a combination of elements that bring about this result, viz.: the length of stroke imparted by the head motion; the side inclination controlled by the hand-wheel; the quantity of wash water, and the end elevation of table. The latter is accomplished by the aid of the adjusting-screws in the bottom bar for the slipper-bearing, and may vary from one-half to one inch in the length of table; normally higher at waste-discharge end than head-motion end of table. Under proper working conditions the visible waste on the deck should occupy the area represented by a triangle, one side of which is the waste-discharge end of the table, and whose base is a line drawn from the lower discharge corner to the center of the wash-water box, and the space between the riffles within this triangle should be kept completely filled with waste material. Should the waste material advance too fast to allow these spaces to remain filled with advancing waste it indicates that the stroke is too long or the end inclination insufficient, and should be adjusted to fill the above conditions.

The receiving launder on the coal-discharge side for the cleaned coal should be provided with a movable diverting-spout, to carry such material to waste as is not suitable to mix with cleaned coal.

The Butchart table, shown in Fig. 123, is designed and built to supply the demand for a better machine, both mechanically and metallurgically, than has been available heretofore—a thoroughly well-built table, capable of treating heavy as well as light tonnages, and withstanding the continuously hard service to which such apparatus is subjected. It is the product of long experience in the operation and construction of concentrating tables, and has been greatly improved since its introduction upon the market five years ago.

Simple design, rugged construction, mechanically correct deck

suspension, permanently efficient tilting mechanism, self-contained and fully enclosed drive, steel base, automatic lubrication of every bearing, accessibility of all parts, elimination of small pieces, great capacity and high efficiency, and its adaptability to all kinds of feed, mark it as a leader in this class of apparatus.

The base of the table consists of two heavy steel channels, bolted to either cast iron or wood sub-sills, which receive the foundation bolts. The channels are bent inwardly at the drive mechanism end, bringing their combined strength toward the longitudinal center and under the point of greatest stress. The cast iron sub-sills have lugs which bolt to the web of the channels

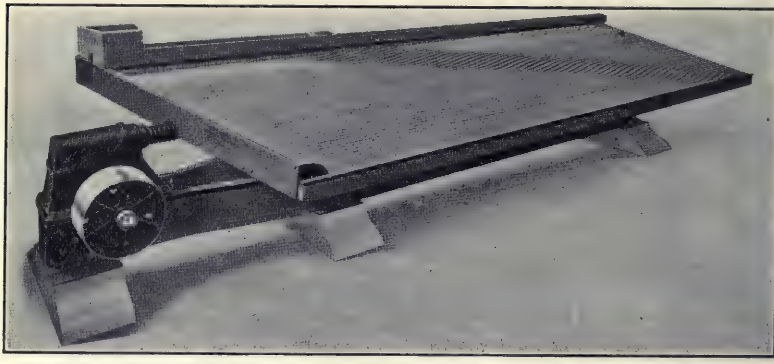


Fig. 123. Butchart Table

instead of through the flanges. The reciprotor is bolted direct to the flanges of the base channels.

On the base channels are bolted two cast iron double pedestals providing suspension bearings for the tilting beams, which carry the deck. The tilting beams are heavy castings which permit suspension of the deck below its center of gravity. Their ends are formed into receptacles for the sliding bearings. The swing of the deck is always on the center line of pull rod and suspension bearings.

Dimensions of the deck, 15 ft. 6 in. by 6 ft. 0 in. Side sills and lengthwise stringers are of carefully selected lumber bolted or riveted to steel plates. The rear end and side are reinforced with a continuous 6 in. steel plate, protected from contact with water by the manner in which the linoleum cover is attached.

The other two sides are reinforced with a continuous steel plate protected by cover boards, so that no iron work is in direct contact with feed or wash water. The reinforced longitudinal stringers are bolted to malleable iron cross trusses which support the deck upon its sliding bearings and will not corrode. The connection to the pull rod of reciprotor or drive mechanism is a strong, easily removable malleable iron casting bolted to two of the longitudinal stringers, insuring proper distribution of the driving stresses. The deck is carried on four sliding bearings, the entire construction being on the principle of the cantilever steel bridge, as distinguished from that of the wooden trestle. The method of construction and suspension prevent sagging, warping or bulging of the deck surface. Upon loosening one nut the deck may be lifted off the mounting.

The mechanism for tilting the deck is one of the most important parts of the concentrating table and has been given special attention. It consists of two pairs of right and left hand bronze screws of large diameter working in internally threaded and protected sleeves actuated by a hand-wheel, shaft and 6 in. bevel gears. One turn of the hand-wheel gives 1 in. change in slope of deck. The tilting screws are directly attached at their upper and lower ends, respectively, to the tilting beams and to brackets bolted to base channels and sub-sills. Wear is automatically compensated and can cause no lost motion in gears, both ends of the deck are moved simultaneously and positively, automatically retained at the desired slope, and twisting of the deck is impossible. Any movement of the hand-wheel, however slight, produces a corresponding change in the slope of the deck. Quick, close and positive adjustment is afforded, all parts are strongly constructed and there are no set-screws, cams, wedges, turnbuckles or other small parts to wear out, work loose, rust, require adjustment or replacement.

The reciprotor or drive mechanism is of a modified toggle type, compact, self-contained and completely enclosed by a cast iron housing and cover which absolutely prevent entrance of dust, water and sand. There are no screw adjustments except for spring tension and bearing caps on drive shaft, no set-screws, bolts or other parts to work loose or require attention. The drive shaft bearings are supported on the base channels, are

automatically oiled and fitted with removable babbit liners which can be replaced in a few moments, no pouring of babbit being required at any time. The drive is at the center of gravity of the deck and through the spring, eliminating all vibration and unnecessary strains on bearings.

The housing serves as a container for a supply of oil sufficient for several months' running. Lubrication of every bearing is accomplished by oil spraying discs carried by the drive shaft. Automatic lubrication results in cool running bearings and great economy in oil consumption, about one pint being required at intervals of three or four months. Oiling requires no attention other than renewal of the supply at long intervals. The mechanism is practically noiseless in operation and nearly fool-proof; there are no bearings to rebabbit and nothing for the repair man to tinker with. No attention or adjustment is required until working parts are worn out. Repair parts are so simple in design and construction that they are furnished at a few cents per pound.

The differential action is strong and proportionate for all lengths of stroke, the range being from ½ to 1¼ in. The stroke adjustment is positive and permanent, is made without the use of screws or additional parts, and cannot be tampered with by the operator without stopping the table. This is one of the most important features of the reciprotor, as it prevents the loss of concentrate frequently caused on some tables by the operator shortening the stroke to stop "pounding" of the driving mechanism or noise in the bearings. Very slight spring tension is required and less power is consequently consumed, this being about 7/10 h.p. regardless of load.

The table, as regularly furnished, is driven from line shaft in the usual manner, but can also be fitted with an individual 1 h.p. motor mounted on the base channels driving by means of a short belt. The individual belted motor offers many advantages, such as decreased power consumption due to absence of long belts and line shafts, convenience in starting and stopping, and freedom to place tables wherever desired regardless of location of line shafts. Dangerous and unsightly shafting, pulleys and belts are done away with, leaving the entire overhead space open for launders, pipes, light, etc. About 16 ft. of 2½ in. 3-ply rubber belt are

required instead of 40 or more feet of 4 in. 4-ply. The motor is protected from dust, water and sand, takes up no floor space, is readily accessible and belt may be tightened without stopping the table. The installation of individual motors costs no more than a single motor with line shaft, hangers, tight and loose pulleys, and necessary belting.

As all oiling is automatic and practically no mechanical adjustments are required, the operator can give his entire attention to regulation of feed, dressing water and the production of concentrates of the desired grade. Little alteration in the slope of the deck is required, insuring a high average efficiency even with inexperienced labor. Under ordinary conditions, about all that is necessary is to adjust the table to the load and then let it alone.

The ultimate value of any concentrating table consists in its ability to separate and save the good coal. However excellent its mechanical design and construction, the table is useless unless concentration be successfully accomplished, and its relative worth is, therefore, largely dependent upon the concentrating surface employed. The causes of the greatly increased capacity and efficiency of this table are found primarily in the riffling system and secondarily in its mechanical features.

On many classes of feed the table will handle from two to five times as heavy loads as can be treated on similar machines, being governed principally by the rapidity with which any particular class of feed will stratify, this action depending upon the characteristics of the material. If feed is properly prepared the values are mechanically carried into concentrate without loss of any portion into middlings or tailings. The means by which these results are obtained may be summarized as follows:

The entire deck surface is riffled and caused to perform useful work other than mere distribution of dressing water.

A few riffles near the higher side of the deck segregate and discharge a large percentage of the readily separable refuse usually present in table feed, the remainder of the surface being free to handle the less easily recoverable refuse, make a two part separations, clean middlings, etc.

The channel between each two riffles is a complete concentrating surface, receiving its load, stratifying, cleaning and discharging its quota of finished refuse; the raw coal does not drift diagonally across the deck and consequently there is no true refuse in the middle product.

The refuse is cleaned between relatively deep riffles, permitting the handling of much heavier loads of raw coal than those systems in which cleaning is done between shallow riffles or upon an unriffled surface.

Classification is accomplished upon the table itself.

The riffles are strips of pine or other suitable wood, cut out with a circular saw, require little hand work and can be made cheaply. To facilitate bending, they are soaked before laying, and practically make their own curves as they are nailed in place. Two men familiar with the work can apply a set in about 3 hours.

The deck surface is in one plane, completely riffled and divided into three distinct zones by deflections in the riffles themselves, the purpose of these areas being stratification, cleaning and discharge of concentrate.

The deepest portions of the riffles, lying directly in front of the feed distributor and extending to the line marking the commencement of the curves, form a series of deep grooves in which stratification is accomplished, the refuse accumulating at the bottoms of the channels and being carried forward by the differential action of the driving mechanism.

The cleaning zone consists of an area in which the riffles are bent toward the higher side of the table, the deflection, in combination with the transverse inclination of the deck surface, producing channels sloping toward the *rear* or feed end of the table and in which currents of water will flow in a direction the reverse of that in which the material is moved by the differential action of the driving mechanism.

The discharge area is supplied with riffles of sufficient depth to prevent drifting of refuse across the deck and to cause its rapid discharge over the end. When it is necessary to employ deep riffles in the discharging zone, a secondary deflection or terminal upward curve is used to prevent too great a proportion of the dressing water being carried over the end of the deck. This arrangement insures a uniform flow of dressing water over the entire deck surface, so that the cleaning action of the upper riffles is duplicated and supplemented by those nearer the discharge side.

The operation of the riffle system is as follows:

The table being started, dressing water is supplied, successively overflows from one to another of the riffles, and upon reaching

the cleaning zone follows the downwardly sloping channels toward the rear or feed end of the table. The quantity of dressing water required is from 150 to 300 gals. per ton of feed, depending upon the fineness to which it is ground.

When feed reaches the upper riffles, stratification quickly ensues and the greater portion of the refuse is deposited in the first 15 channels, the remaining refuse being caught further down the table. The differential action of the reciprotor moves the entire mass forward until it reaches the cleaning zone. Here it meets the streams of dressing water flowing in the opposite direction and the superficial layer of good coal is washed away, while the refuse, by reason of its greater specific gravity, continues its forward movement. As the riffles in the cleaning zone are not parallel to the line of table motion, they produce a transverse agitation or ''side-shake,'' similar in effect to that of the vanner, causing any remaining good coal to be brought to the surface, whence it is washed back into the main body of middlings or tailings. When the refuse reaches the further side of the cleaning zone, it has been freed from good coal and passes into the discharge zone of straight riffles, which carry it to the end of the deck.

The following table gives the results obtained with a Butchart table treating Illinois coal, which contains at least 2 per cent. of organic sulphur. These results were not obtained during a test run, but in the course of actual washing operation.

Results of a Butchart Table Treating 3/16 in. Unsized Illinois Coal

Raw Coal		Washed Coal		Refuse	
Ash per cent.	Sulphur per cent.	Ash per cent.	Sulphur per cent.	Ash per cent.	Sulphur per cent.
13.72	3.11	6.11	2.29	49.19	9.38
13.80	3.16	6.37	2.21	57.27	10.16
13.07	3.30	6.60	2.24	51.75	10.18
13.10	3.20	6.00	2.13	45.30	8.14
13.70	3.16	6.15	2.16	50.10	9.93
13.20	3.23	6.40	2.27	49.20	10.04
13.65	3.42	6.31	2.21	55.15	8.78
13.34	3.20	7.14	2.32	54.50	9.75
12.64	3.05	6.36	2.16	51.60	10.33
14.30	3.20	5.90	2.20	45.80	8.50
Average 13.45	3.20	6.33	2.22	50.97	9.52

Table 34

The *Deister-Overstrom Table* is shown in Fig. 124.

The primary features of the construction of the Deister-Overstrom table are the diagonal deck and the "pool" riffling. By a combination of these in the treatment of coal, highest efficiency is secured in extraction of good coal with a clean refuse and but little middle product. High extraction and clean refuse are secured: (1) By the diagonal disposition, in the line of travel taken by the coal, of the principal concentrating section of the deck, which insures the coal being retained thereon for the longest possible time; (2) all riffles are placed parallel to the line of motion and at an angle to the coal discharge. This secures the advantage of deflected riffles without whipping action, and gives to the stratified material a free and unobstructed movement towards the refuse edge of the table. Clean refuse is produced by the spreading out in a thin or shallow sheet of the refuse bed, thus exposing all of the fine coal to the action of the dressing water.

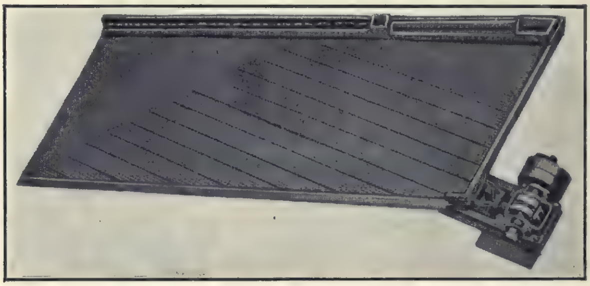


Fig. 124. Deister-Overstrom Table

A small proportion of middle product is maintained by reason of the non-congestion of the refuse at the middling corner. The spreading out of the refuse, which thus prevents banking against the good coal, enables all of the free refuse to come forward without interruption.

The coal traversing the deck surface takes an oblique course, which is the resultant, mainly, of the action on its particles of two forces, the gravital action due to the side tip of the deck, assisted by the side wash of the feed and the dressing water, and the forward and lengthwise impulse imparted through the deck

surface by the differential or "kick" of the motion assisted by the riffles. Assuming the same tip in all cases, the deeper the riffling, the deeper and narrower will be the pulp zone as it traverses the deck, and the less its angle of obliquity.

Shallow riffling has just the opposite effect. It permits the coal to spread out in a broad, thin zone. In concentrating on a long and narrow rectangular deck, the riffling must be relatively deep to confine the operation to the working area of the deck and deliver the coal and the refuse at their proper places. On such a deck, therefore, the pulp occupies a comparatively narrow zone, leaving large unoccupied areas which contribute but slightly to the effectiveness of the operation.

The disposition of the deck area of the Deister-Overstrom table is such as to take the greatest possible advantage of the natural obliquity of the pulp flow. Shallower riffles can, therefore, be used on the Deister-Overstrom deck (the maximum height on Deister-Overstrom sand tables is only 3/32 in.) and the pulp spreads out in a thin zone. This permits a freer inter-movement of the particles, a better stratification and, therefore, a better concentration and separation of the good coal from the refuse.

Head Motions. The Deister heavy-duty head motion has been in successful use for the last ten years. Its design embodies the combination of two differential motions, which are adjustable in varying relation, to produce a gentle or a very sharp differential or "kick" in the movement transmitted to the deck. Both the length of stroke and degree of differential are adjustable. Changes can be made in either while the table is in operation.

The stroke is regulated by turning a hand piece. Turning to the right will lengthen it. Fig. 125 gives an X-Ray picture of this head motion.

The variation of differential is secured by shifting the lug of the adjustable eccentric 14 (see Fig. 125). Usually the best results are obtained when this lug (measuring from the rear inside edge of its cup) is 7/8 in. forward (toward the table) from a vertical through the center of the shaft.

Shifting the lug toward the table will have a tendency to hasten the advance of the settled mineral toward the concentrate edge, while the reverse has a retarding effect. In general the lug position for a proper differential will lie somewhere between the

vertical and a forward shift of 45 deg. In shifting the adjustable eccentric loosen the nuts of the cap holding the bearing of which it is an extension. After the adjustment is made be sure that the nuts are tight. It is advisable not to move the lug forward or backward more than ¼ in. at a time, as a small adjustment will make a very perceptible difference in the movement of the pulp. The motion should run forward or towards the table.

This motion is equipped with an 8 in. roller eccentric and 16 in. driving pulley.

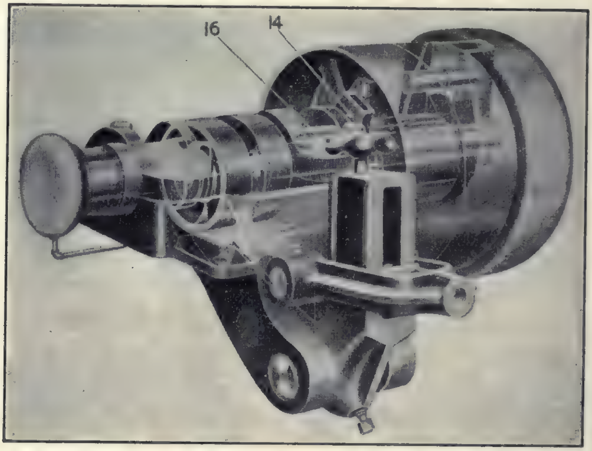


Fig. 125. Deister Heavy-Duty Head Motion

The Overstrom Head Motion is strong, compact, exceedingly simple and has few wearing parts. A variation in stroke from 9/16 in. to 15/16 in. can be secured by the adjusting screw. The central position of the block and screw gives a ¾ in. stroke. This head motion should be run forward or toward the table. Fig. 126 shows the construction details of the Overstrom Head Motion.

The *Overstrom Motion* and the *Deister Heavy-Duty Motion* are interchangeable in their use on the Deister-Overstrom diagonal deck tables. Connection between the head motion and the rocker arm is by means of a connecting link and steel yoke.

Operation Data on the Deister-Overstrom Concentrating Table

Recommended speed in r.p.m.	240 to 265
Length of stroke	¾ in. to 1 in.
Driving pulley dimensions	16 in. by 4 in.

Recommended belt dimensions....................	3 in., 3-ply belt
Maximum power required.......................	1½ h.p.
Recommended percentage of solids in feed.........	35 per cent.

Figs. 127 and 128 show a typical arrangement of a table coal washing plant designed by the Deister Concentrator Company.

The Deister Plat-O Coal Washing Table is shown in Fig. 129. The distinctive feature of this table is an elevated plateau with inclined approaches. The table requires from ¾ to 1 h.p. and

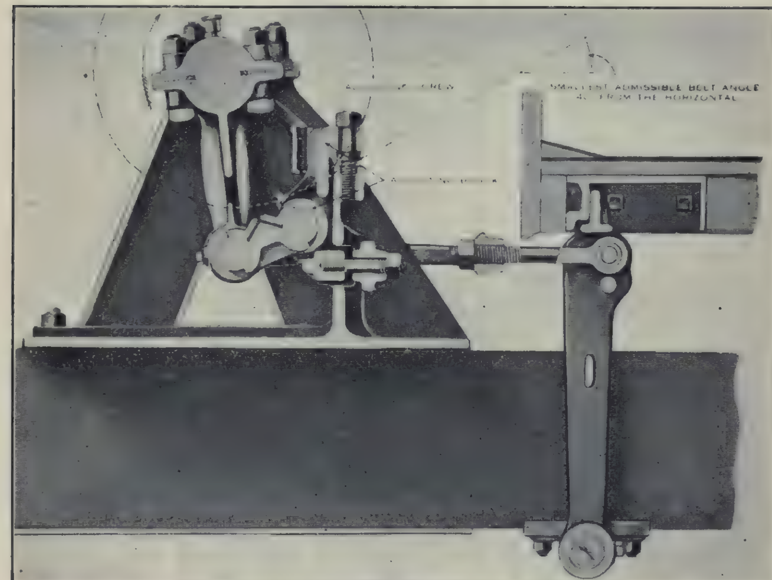


Fig. 126. Overstrom Head Motion

occupies a floor space of 7 ft. by 17 ft. 4½ in. From 3 to 5 gal. of dressing water are required per minute. The capacities of the table are as follows:

Through ¼ in. screen from........................	8–10 tons
Through ⅜ in. screen from........................	10–12 tons
Through ½ in. screen from........................	11–13 tons
Through ⅝ in. screen from........................	12–14 tons

The *Overstrom Universal Table* has some features in which it differs from all other devices of its kind.

The head-motion consists of an unbalanced pulley driving loose

A=Length of Building
B=Length of Table Storage Bin
C=Coal Washing Tables
D=Table Storage Bin
E=Conveyor (R. B. & C. H. to Table Storage Bin)
F=Screw Conveyor Table Feeder
G=Washed Coal Launder
H=Tailing Launder
J=Washed Coal Dewatering Elevator
K=Tailing Elevator,
L=Overflow Launder (Dewatering Elevator to settling Tank)
M=Conveyor to washed Coal Storage Bin

CAPACITY IN TONS PER HOUR	A	B	C
100	108'-0"	72'-0"	12
200	180'-0"	144'-0"	24
300	252'-0"	216'-0"	36
400	324'-0"	288'-0"	48
500	396'-0"	360'-0"	60

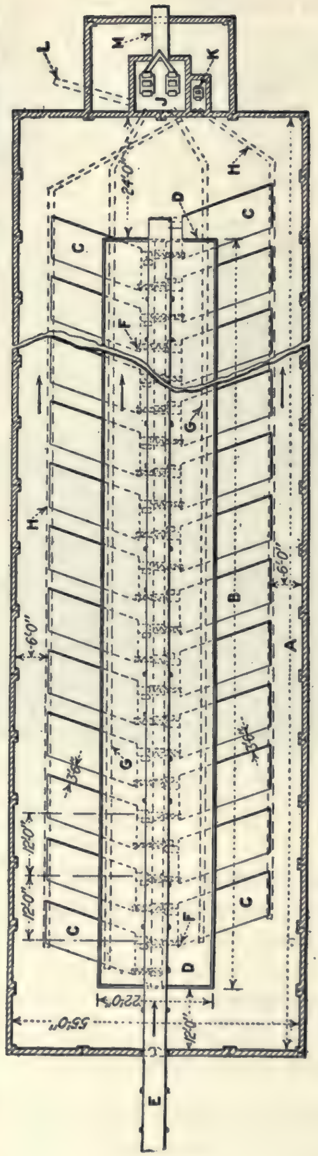


Fig. 127. Coal Washing Plant Using Tables. Plan View

on a shaft rigidly attached to the table deck, this motion being limited by a fixed stop on one end of the stroke and a cushion spring at the other, thus doing away with all eccentrics, cams and toggles.

There are no bearings under the deck, but it is supported from the floor frame by laminated wooden springs which allow the table to swing lengthways as an inverted pendulum, the motion being in the arc of a circle, the riffles also being laid out in arcs practically parallel to the line of motion.

The supporting legs are inclined slightly backward toward the

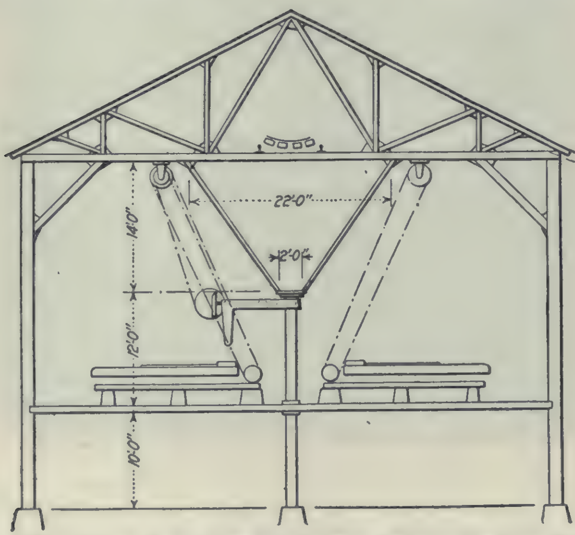


Fig. 128. Cross Section Through Coal Washery Using Tables

head-motion, causing the table to rise on its forward stroke. On account of the method of imparting reciprocating motion to the table, it will automatically increase or decrease the stroke with a heavier or lighter feed.

Fig. 130 illustrates the Overstrom universal concentrating table. On this table the motion of the deck is practically parallel to the direction of the riffles. The advantages claimed for this table are as follows: As the deck is tilted, the height of the riffle tips above their feed ends increases. The refuse must climb the height corresponding to the curvature of the riffles and the tilt

of the deck. The grade increases as the riffle tips are approached, causing more and more of the good coal to fall back and pass over the coal discharge side. The separation of coal and refuse is gradual and takes place over a large surface. It is not confined to one congested line or zone. The motion of the deck, parallel to the riffles throughout their length, causes the refuse to travel with the riffles, not against an arbitrary curve,

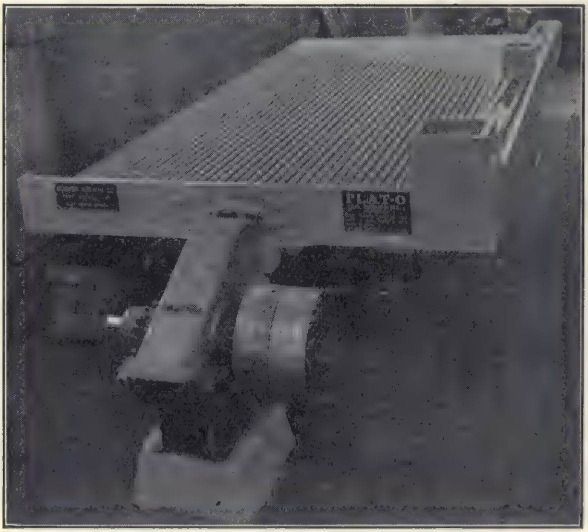


Fig. 129. Deister Plat-O Table

either in riffles or deck. Therefore the travel is rapid and the capacity is great.

J. B. Morrow, in his paper on "Coal Washing on Concentrating Tables," has the following to say:[1]

> The chief virtue of the table as a coal cleaner lies in its sensitiveness to adjustment and full visibility of the process, together with the ease with which the quality of the product may be varied. The variables as they affect practice are as follows: (1) Length of stroke, (2) revolutions per minute, (3) lateral inclination, (4) longitudinal inclination, (5) dimension and spacing of riffles.
>
> As an illustration of what can be accomplished on a machine of this kind,

[1] "Coal Washing on Concentrating Tables," by J. B. Morrow. *Coal Age* (Vol. 16, No. 13, 1919).

the figures that follow show the result of a test run made on an Overstrom-Universal table.

The feed to the table, which consisted of jig hutch and reground middlings ranging in size from ⅜ in. down to fine sludge, is a harder proposition to handle than the primary coal on account of the concentration of the bony matter, some of which will only have a small differential in specific gravity to distinguish it from the rock or coal.

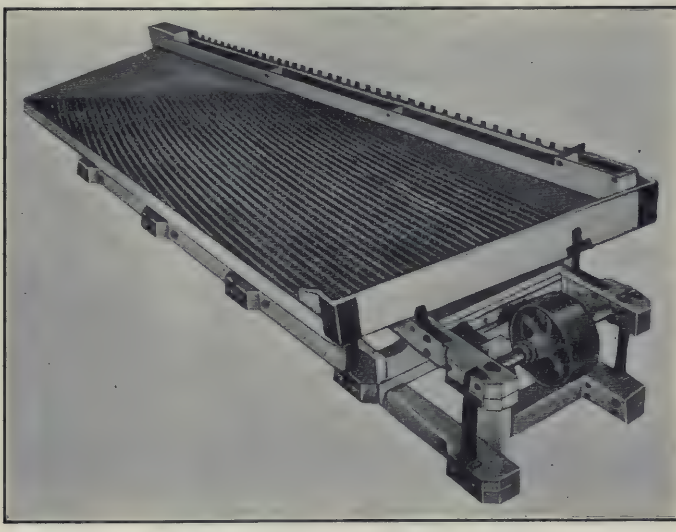


Fig. 130. Overstrom Universal Table

The tonnage handled was five tons per hour, having a composition, as shown by the specific gravity separation, of

46 per cent. feed	at 48.0 per cent. ash
54 per cent. feed	at 11.3 per cent. ash
100 per cent. feed	28.2 per cent. ash

The results obtained were:

49	per cent. clean coal with 11.6	per cent. ash
40.6	per cent. clean rock with 48.7	per cent. ash
10.4	per cent. middlings with 27.5	per cent. ash
100	per cent.	27.66 per cent. ash

This is equivalent to a recovery of 91 per cent. of the coal. If the middlings were put in with the waste, it would give 51 per cent. waste with an ash of 44.1 per cent. as compared with 48.7 per cent. in the theoretical separation, carrying 10 per cent. of recoverable coal.

In practice, these middlings from the primary machines are again treated

on a table using a shorter stroke and lower riffles and the final waste from the mill contains an average of 5 per cent. of recoverable coal, or, expressed in another way, 99 per cent. of the recoverable coal in the feed is reclaimed.

In ore dressing the line between concentrates and tailings can be usually clearly defined, but with coal this is not possible. Between clean coal and pure refuse we find a more or less wide area containing the so-called middle products. Therefore it becomes necessary to make either three products or to establish the division between coal and refuse at the most economical and efficient point. Fig. 131 shows clearly the segregation of the particles

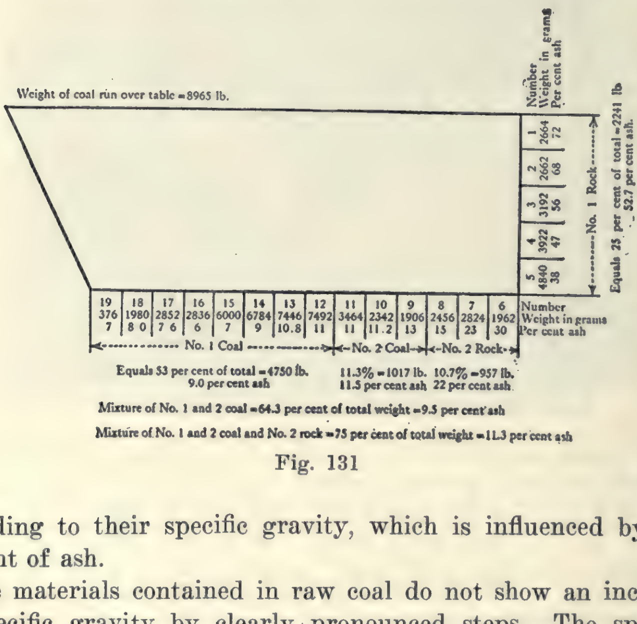


Fig. 131

according to their specific gravity, which is influenced by the amount of ash.

The materials contained in raw coal do not show an increase in specific gravity by clearly pronounced steps. The specific gravities increase by infinitesimal increments, and if we plat the specific gravities of the different materials we will get a continuous ascending curve and not a broken straight line interrupted by distinct steps.

The proper washing of fine coal has for a long time been an uncertain undertaking. With the advent of concentrating tables, however, the difficult problem of washing fine coal has been solved in a satisfactory manner. With coking coal there now exists the

possibility of abandoning the use of jigs entirely, by crushing all the coal to the required fineness and treating it on tables. This fine crushing will liberate more effectively the bone coal, and tables will therefore produce cleaner washed products. The reason for the foregoing is obvious. The finer the coal is crushed the more complete is the physical separation of coal from its impurities, and it only remains now to accomplish the segregation of the coal from them.

Tables require little power, about 1 h.p. is sufficient to operate one table. The supporting structure for a table can be much lighter than for jigs, and the building housing such machines does not need to be so massive.

Besides primary washing, tables can be used to good advantage either for the rewashing of recrushed middle products or for the rewashing of the sludge recovered from the water clarification. For this latter purpose a slightly different type of machine should be used, resembling the slime tables used in ore dressing. Concentrating tables can be used economically at every washery, and at present they represent the most feasible apparatus for treating fine coal and sludge. They unquestionably offer many advantages in an economical as well as purely technical way.

The cost of installation is low, they require less expensive buildings and foundations than jigs. The cost of operation is considerably less than that of jigs on account of the small power required, the reduced wear and tear and less supervision. One operator can watch five times as many tables as jigs. In regard to capacity tables are equal to jigs treating the same kind of coal. Outputs up to 12 tons per hour have been recorded for one table. Fig. 131 indicates clearly the manner in which the separation is effected on one of these machines and shows the possibility of making any kind of washed product or refuse by simply dividing the outflowing product at any desired point along the side or end of the table.

The great advantage of a table lies in the fact that the process of separation is immediately before the eye and any desired change can be made without interrupting the operation. The outflow of the materials is visible, and by a judicious regulation of the stroke, the water supply and the slope of the table, the operator has full control over the process.

The following tables show some results obtained in table work:

	Weight, Lb.	Per Cent.	Ash, Per Cent.	Sulphur, Per Cent.
Raw coal	481	100	12.50	2.67
Washed coal	406	84.4	6.71	2.04
First middle product...	30.5	6.3	29.19	5.72
Second middle product..	38.5	8.0	42.65	6.02
Refuse	6.0	1.3	65.00	10.54

SEPARATION BY SPECIFIC GRAVITY

	Lighter than 1.37 sp. gr.	Heavier than 1.37 sp. gr.	
Washed coal..........	82.2 per cent.	17.8 per cent.	
	Lighter than 1.35 sp. gr.	Between 1.35 and 1.50 sp. gr.	Heavier than 1.50 sp. gr.
First middle product...	12.5 per cent.	21.0 per cent.	66.5 per cent.
Second middle product.	11.4 per cent.	12.7 per cent.	75.9 per cent.
	Lighter than 1.45 sp. gr.	Heavier than 1.45 sp. gr.	
Refuse	2.2 per cent.	97.8 per cent.	

RESULTS OBTAINED ON TABLES WITH SULPHUR ELIMINATION

	Raw Coal	Washed Coal	Side Middlings	End Middlings	Refuse	Elimination in per cent.
Per cent. sulphur	3.31	1.47	1.50	3.02	24.30	55.7
	3.47	1.25	1.38	2.33	23.28	63.9
	3.41	1.37	1.55	2.43	14.68	59.9
	3.12	1.30	1.37	2.55	16.94	58.3

Raw coal sulphur, per cent.	2.76	2.93	2.76	3.21	3.59	3.75	3.08	3.53	4.06	4.74
Washed coal sulphur, per cent	1.26	1.38	1.29	1.48	1.43	1.88	1.59	1.37	1.37	1.34
Elimination, in per cent. ..	54.3	52.9	53.3	53.9	60.2	49.9	48.4	61.2	66.2	71.7

CHAPTER XXIII

FURTHER TREATMENT OF THE PRODUCTS OF A JIG

The products delivered from the jig cannot be used without further treatment. All the products require a more or less extensive and difficult subsequent preparation before they can be placed on the market. This after-treatment depends largely upon the size of the coal. Coarse coal must be dewatered, classified and delivered into the loading or storage bins, avoiding thereby breakage and abrasion as much as possible.

Fine coal must be dewatered and delivered into the bins or railroad cars. Middle products are either first crushed and then delivered to rewash jigs or are delivered to these machines without previous crushing. The refuse from the rewash jigs is combined with that from the primary jigs, and the washed coal is either mixed with that from the primary jigs or separately stored in bins as boiler-house fuel, according to its degree of purity. The wash water must be clarified before it can be put back into circulation.

The sludge recovered by the process of water clarification can be subjected to a further treatment, but in any case it must be dewatered before it can be mixed with the washed products. If the sludge is of such a character, however, that subsequent treatment will not improve it, it must be wasted and thrown on the refuse dump.

The refuse is delivered into refuse storage bins and from there by means of self-dumping cars or similar devices carried to the dump. Before delivery into the bin, however, the refuse must be dewatered by means of a perforated bucket elevator; the overflowing dirty water is clarified and put back into circulation. The resulting sludge is deposited on the refuse dump. If the refuse contains pyrites, a separate installation for its recovery would be advisable. The economic value of such a plant, however, would depend a great deal upon the market value of sulphur.

CHAPTER XXIV

SUBSEQUENT TREATMENT OF WASHED NUT COAL

The nut coal as it leaves the jigs has been either subjected to a preliminary sizing or it has been washed unsized. Even if the raw coal has been sized before washing, a subsequent sizing becomes necessary on account of the degradation suffered by it in the jigs. Therefore the different sizes of washed coal are not kept separate after washing, but all the coal coming from the coarse coal jigs is conveyed together to the final sizing screens. This conveying is best accomplished by means of the wash water in sluice-ways. Usually all the washed coal is sluiced into a settling tank, out of which a dewatering elevator lifts it to the sizing screens, which are located on top of the loading bins. To secure a still better draining off of the water, a dewatering screen is placed ahead of the sizing screens.

Dewatering. For dewatering of nut coal either fixed or movable screens are used. Fixed screens have the disadvantage of taking up too much height on account of the necessarily steep pitch at which they must be placed to let the coal slide down. The coal is also subjected to a considerable drop, which causes some degradation.

Shaking screens or revolving screens are to be preferred. Fig. 61 (page 119) shows a dewatering and resizing plant. This arrangement has only single screens and the coal is sized from fine to coarse. A resizing screening plant from coarse to fine is shown in Fig. 132.

This screening plant consists of two separate screens "a" and "b." Both screens are driven from one shaft "c," having two cranks placed at 180 deg., which arrangement balances the two screens.

In most of the Stewart type washeries for fuel coal the washed material is sized in revolving screens, which are located over

a long and narrow sludge recovery tank. The different sizes of coal are conveyed by spouts to the foot of separate elevators which carry the sized coal to the respective loading bins. The flow sheet on page 362 and the general plan of a fuel coal washery on page 369 shows such an arrangement. Two revolving screens are used in tandem. The first screen has three sections with different perforations. In the first section all the No. 4 and No. 5 coal together with the wash-water are screened out. In the second section No. 3 coal is separated and the undersize of the third section is No. 2 coal, while the oversize is No. 1 coal. The No. 4 and No. 5 coal and all the wash-water are sluiced into the second screen which makes No. 5 as the undersize and No. 4

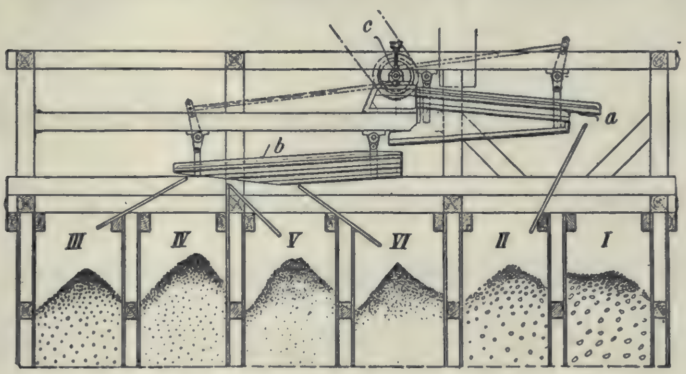


Fig. 132. Resizing Screens on Top of Washed Coal Bins

as the oversize. The No. 5 drops in the sludge tank and is dewatered and carried out by a dewatering elevator, which discharges the coal on a shaking screen with very fine perforations, where several sprays of fresh water wash off the adhering fireclay and the muddy water.

The following tables taken from Bulletin No. 69 of the Engineering Experiment Station of the University of Illinois, entitled "Coal Washing in Illinois," by F. C. Lincoln, give the sizes and capacities of revolving screens used for resizing washed coal which had been sized prior to washing.

Table 36 gives data of revolving screens used for sizing washed coal which had not been sized before washing.

Screen No.	Type	Length (Feet)	Dia. (Feet)	Slope (Degrees)	R.P.M.	Peripheral Speed Feet per Minute	Openings Diam. (Ins.)	Openings Shape	Length of Screening Surface (Feet)	Feed Diameter (Inches)	Feed Tons per Hour	Per Cent. Through Screen	Sq. Ft. Screen Per Ton per Hour
18	Cylindrical	7	3	3	15	141	½	Round	7	1–¾	28	(Breakage only)	2.4
19	"	7	2½	3	15	118	¾	"	7	....	..	" "	...
20	"	8	4	4	18	226	¼	"	8	¾ & ½–0	52	50	1.9
21a	"	19½	6	4½	12	226	¾	"	6	3–9/16 sq.	53	(Very little)	2.6
b							1⅛	"	8	3–¾	53	29	2.8
c							1¾	"	5½	3–1⅛	39	49	2.7
22a	Roller cylindrical	16	5	4	16	251	¼	"	12	¾&9/16 sq.–0	58	56	4.3
b							⅜	"	4	¾&9/16 sq.–¼			
23	Cylindrical	8	3	2½	36	339	¾	"	8	1⅛–¾	16	(Supplementing Screen No. 21a)	4.7
24	"	8	3	2½	36	.339	1⅛	"	8	1¾–1⅛	20	(Supplementing Screen No. 21b)	3.8
25	"	8	3	2½	36	339	1¾	"	8	3–1¾	19	(Supplementing Screen No. 21c)	4.0
26	"	8	4	2½	36	452	¼	"	8	¾–¼ & ⅜	32	(Supplementing Screen No. 22a)	3.1
27	"	8½	3	5	24	226	1¾	"	8½	3–1¾	9	(Breakage only)	9.0
28	"	8½	3	5	24	226	1¾	"	8½	3–1¾	9	" "	9.0
29	"	8½	3	5	24	226	1¾	"	8½	1¾–1	9	" "	9.0
30	"	8½	3	5	24	226	1¾	"	8½	1¾–1	9	" "	9.0
31	"	8½	3	5	24	226	¾	"	8½	1–¾	15	" "	5.3
32	"	6½	3	5	24	226	1	"	6½	1¾–1	18	(Supplementing Nos. 27 & 28)	3.5
33	"	10½	4	3½	30	377	¼	"	10½	¾–0	50	36	2.6
34a	Double-jacketed, cylindrical	5½	2	2½	15	94	1	"	5½	3–2	6	(Breakage only)	5.8
b			3			141	¾	"	5½			" "	
35	Cylindrical	7	2	5	15	94	¾	"	7	2–1	5	" "	8.8
36a	Double-jacketed, cylindrical	5½	2	3	15	94	1	"	5½	2–1	12	" "	2.9
b			3			141	¾	"	5½			" "	
37	Cylindrical	7	2	5	15	94	¾	"	7	1–¾	5	" "	8.8
38	"	8	4	5	24	301	¼	"	8	¾–0	32	36	3.1
39a	Double-jacketed, cylindrical	..	..	....	15	...	¾	"	8	3¾–¼	..	......	...
b							1	"	..	3¾–¾	..	......	...
c							1¾	"	..	3¾–1	..	......	...
40a	Double-jacketed, cylindrical	7	3	6	14	132	2½	"	7	3½–2¾		(Breakage only)	
b			2			88	¾	"	7		5	" "	8.8
41a	" "	7	3	6	14	132	2½	"	7	3½–2¾		" "	8.8
b			2			88	¾	"	7		5	" "	8.8
42a	" "	7	3	7	14	132	1¾	"	7	2¾–1¾		" "	

TABLE 35

Screen No	Type	Length (Feet)	Dia. (Feet)	Slope (Degrees)	R.P.M.	Peripheral Speed Feet per Minute	Openings Diam. (Ins.)	Openings Shape	Length of Screening Surface (Feet)	Feed Diameter (Inches)	Feed Tons per Hour	Per Cent. Through Screen	Sq. Ft. Screen Per Ton per Hour
65	Cylindrical	9⅓	4⅔	5½	40	588	5/16	Round	9⅓	3½–0	..	......	...
66	"	10	5	4	14	220	¼	"	10	3½–0	108	......	1.5
67a	Double-jack-	21	5 & 8	Axis level	15	267	1⅜	"	9	3½–¼	..	......	...
b	eted, coni-					315	1	Square	6	3½–1⅜	..	......	...
c	cal					356	1¾	"	6	3½–1 sq.	..	......	...
d		9	7 & 8⅓			362	⅞	Round	9	1⅜–¼	..	......	...
68	Cylindrical	9⅓	4	5	20	251	⅜	"	9⅓	⅝–0	..	......	...
69	Conical	6½	4 & 5	Axis level	25	353	5/16	"	6½	3–0	..	......	...
70	Roller	16	6	5	12	226	⅜	"	16	1¼–0	125	39	2.4
71	Cylindrical	16	6	5	12	226	⅜	"	16	1¼–0	125	39	2.4
72	Cylindrical	12	4	5	20	251	¼	"	12	¾–0	61	48	
73	"	7	3	7	11½	108	1½	"	7	3–1¾	109	(Supplementing Shaker Screen No. 27)	0.6
74	"	7	3	7	11½	108	1	"	7	1¾–1⅛	94	" "	0.7
75	"	7	3	7	11½	108	⅜	"	7	1⅛–¾	74	" "	0.9
76a	"	18	5	4	18	283	¾	"	12	3–0	113	61	1.7
b							1¾	"	6	3–¾	44	3	2.2
77	"	12	5	3	18	283	⅜	"	12	¾–0	69	62	2.7
78	"	12	4	2	21	265	1/16	"	12	⅜–0	43	(Rinsings only)	3.5
79	"	8	4	5	15	180	1¾	"	8	3–1¾	1	(Supplementing Screen No. 76b)	100.
80	"	7	3	7	15	141	1⅛	"	7	1¾–¾	22	50	3.0
81	"	7	4	7	15	188	1⅛	"	7	1¾–¾	22	50	3.0
82	"	8	4	4	18	226	{ ¾ { 1	" "	4 } 4 }	....	..	(Supplementing Screen No. 76c)	...
83	"	12	5	5	16	251	⅜	"	12	¾–0	28	36	6.7
84	"	12	5	5	16	251	⅜	"	12	¾–0	28	36	6.7
85a	"	16	4	5	18	226	2	"	8	2½–0	..	......	...
b							1¼	"	8	2–0	..	......	...
86	"	8	4	4½	20	251	¾	"	8	3–0	..	......	...
87a	"	12	4	5	18	226	2	"	6	3–¾	..	......	...
b							1¾	"	3	2–¾	..	......	...
c							1	"	3	1¾–¾	..	......	...
88a	Triple-jacket-	15	4 & 7½	Axis level	12	216	1¾	"	15	3–7/16 & ⅜	114	69	2.4
b	ed, conical	16	6½ & 10			311	1¼	"	16	1¾–7/16 & ⅜	78	51	5.3
c		17	8 & 12			377	¾	"	17	1¼–7/16 & ⅜	50	67	10.7
89	Cylindrical	11	3	8	20	188	¾	"	11	1¼–¾	16	(Supplementing Screen No. 88c)	6.5
90a	Triple-jacket-	14	4 & 6	Axis level	8½	133	1¾	"	14	3½–0	106	24	2.1
b	ed, conical		6 & 8			188	1	"	14	1¾–0	81	28	3.8
c			7½ & 9½			227	¾	"	14	1–0	58	27	6.4
91	Cylindrical	8	4	4	16	201	5/16 & ¼	"	8	¾–0	21	45	4.8
92	"	8	4	4	16	201	5/16 & ¼	"	8	¾–0	21	45	4.8
Average	....	....	....	....	18	245	....	....	....	....	....	....	6.5

CHAPTER XXV

THE STORAGE OF WASHED NUT COAL

It is desirable to load the washed coal into the railroad cars as quickly as possible so as to pass a continuous string of cars through the washery and to avoid delays in switching. This can not be accomplished by loading directly from the jigs. It is necessary to accumulate the washed coal in large quantities in bins. For each size of coal a separate bin or compartment must be provided and in some washeries a mixing conveyor is installed on top of the bins to permit the mixing of two or more sizes.

The location of the loading bins is determined by the loading tracks, since the loading chutes may be either directly over the cars or to one side of the track.

The size of the bins depends upon the capacity of the washer and the amount of each size made. It is, however, considered better to make all the compartments of the same size and large enough to hold two carloads each or about 100 tons. This permits loading of railroad cars without waiting for more coal to come from the jigs to make a full carload.

The washed coal bins on account of their great capacity have a considerable height and it is not permissible to let the coal drop direct from the screens, without breaking the fall. Several methods are in use to prevent this injurious drop. Simple chutes are shown in Fig. 132. Such chutes are sufficient for hard coal, but for the more friable varieties spiral chutes as shown in Fig. 61, or so-called telegraph chutes are used. Spiral chutes are of a simple construction and comparatively cheap, but the pitch of the spiral must be steep in order to allow the coal to slide easily. Telegraph chutes are mostly built of wood and lined with steel plates. They are arranged on the inside of the bin walls and let the coal slide down without perceptible drop.

To prevent the freezing of the washed coal in the winter time steam heated discharge gates are used and the room under the bins is housed in and steam heated.

CHAPTER XXVI

THE CRUSHING OF COAL

Coal as it comes from the mine is crushed for three purposes:

1. The crushing of the lump coal into smaller sizes, suitable for washing, results at the same time in the breaking off of the adhering slate and pyrite.

2. The crushing of the middle products, to free the good coal from bone and slate.

3. The crushing of the washed nut coal to make it suitable for coking.

The Crushing of Lump Coal. The size of a crushing plant depends upon the percentage of lump in the run of mine coal and on the demand for lump coal. The condition in the mine and the demand for lump coal are not always of such a uniformity that either a crushing plant would not be required or that such a plant could be operated with a constant capacity. Unforeseen changes in the operation of a mine, such as a shut-down of a certain section of the mine or changes in the characteristics of the coal, etc., or sudden heavy demands for certain sizes result at times in great changes in the amount of crushing a plant has to handle.

Sometimes a crushing plant must handle a large tonnage of lump coal in a short time in order to fill orders for a certain size, whereas at other times the plant will be idle. Consequently a crushing plant should be designed for large capacities. Crushers require considerable power. As a result, if crushers are driven by motors, which drive at the same time other steady-running machinery, the motors must be much bigger than are required for the steady-running machinery, if the crushing plant is idle. This means an inefficient power consumption and for this reason a crushing plant ought to be driven by independent motors.

Careful Crushing. The crusher that produces the largest percentage of the desired size with the least amount of over and

undersize, especially dust, is the best. The fact that the efficient washing of coal increases in difficulty as the size of the material diminishes demands that the production of fine raw coal should be restricted to a minimum. For fuel, the raw coal is usually crushed to pass a 3 in. ring, but for coking coal the most efficient size has not been fully determined and depends to a great degree upon the characteristics of the raw coal. It varies between ¾ and 1¼ in. T. J. Drakeley shows in his "Scientific Study on Coal Washing" that the maximum reduction in ash content is obtained when washing material of a diameter of about 1¼ in. and he says that any reduction in the diameter beyond this limit results in a rapid decrease in the efficiency of the separation. For a washery to be used advantageously the material sent to it must consist of a merely mechanical admixture of impurities with coal. A washery obviously fails entirely in dealing with coal that is "intergrown" with impurities. Such raw coal needs judicious crushing so that the impurities are freed from their attachment to the coal without undue production of fines. Washing then may be an effective means of purification. Crushing can not be indulged in to an unlimited extent. Jungst concluded from his investigations that the limit of fineness according to quality is $\frac{1}{50}$ to $\frac{1}{120}$ in. Experience with American washeries show that coal finer than $\frac{1}{10}$ in. can not be dealt with profitably.

There appears to be no known process for separating the slate dust from the finest raw coal dust. Although in such cases, where the whole of the washed coal is sent to the coke ovens, there is no waste, it should be borne in mind that the fine washed coal is always of an inferior quality and that a coal which has been washed more successfully in a larger size might yield a better coke. Drakeley has compiled a table showing the average concentration and the ash contents of different sizes up to 2 in. in diameter.

From this table it is to be concluded that in washing the larger sizes a higher concentration of the valuable constituent is effected. Therefore, every effort should be made to limit the breakage, so as to preserve the large pieces of material. Any preventable reduction of the diameter of the particles of raw coal to less than ¾ in. involves a considerable lowering of the attainable quality of the washed product.

CONCENTRATION OF FLOAT PARTICLES IN AND ASH CONTENT OF THE VARIOUS SIZED WASHED COAL

Size	Average Diameter	Average Concentration of the Float Particles	Average Ash Content
Inches	Inches	per cent.	per cent.
0–⅛	1/16	90.14	10.34
⅛–3/16	5/32	90.75	9.84
3/16–¼	7/32	91.80	9.15
¼–5/16	9/32	92.19	9.03
5/16–⅜	11/32	92.57	8.81
⅜–½	7/16	93.90	8.06
½–11/16	19/32	94.41	8.04
11/16–¾	23/32	94.41	8.01
¾–1	⅞	94.70	7.92
1–1⅛	1 1/16	95.07	7.79
1⅛–1⅜	1¼	95.14	7.73
1⅜–1½	1 7/16	95.14	7.76
1½–1¾	1⅝	95.15	7.82
1¾–2	1⅞	95.15	7.85
Average raw coal..................		81.21	16.82

TABLE 37

Types of Crushers. For the crushing of coal, needle crushers, double roll crushers, single roll crushers, hammer crushers and

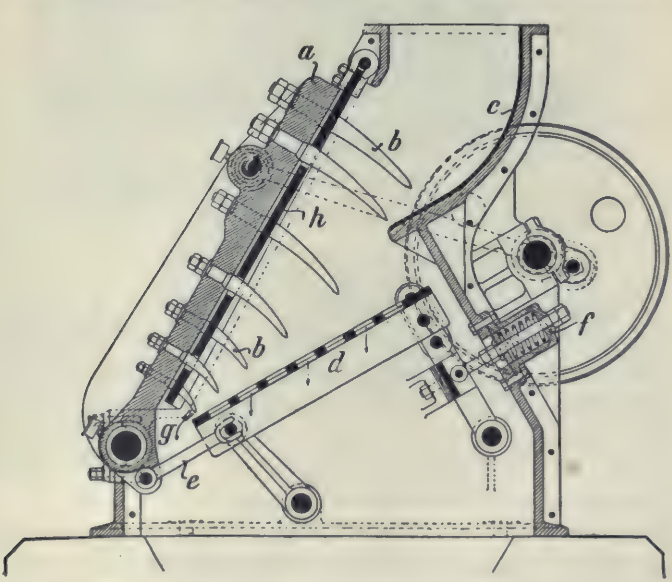


Fig. 133. Needle Crusher for Coal

Bradford breakers are used. Needle crushers are used largely in Europe but thus far have not found great favor with the American coal operator. Figs. 133 and 134 show such a crusher.

The swinging plate "a" has rigidly fastened to it steel needles "b" which decrease in length and diameter from top to bottom. The coal drops on the plate "c" under the biggest and longest needles which crack the largest lumps. The coal then drops on the shaker screen "d" which derives its motion from the shaft

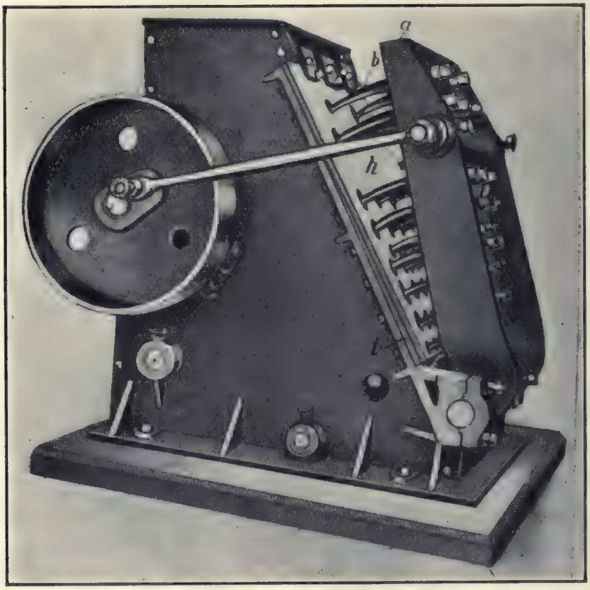


Fig. 134. Needle Crusher

of the swinging plate by means of a lever "e." This screen is cushioned on its rear end by a spring "f." The perforations of the screen determine the size of the coal. On the screen the coal is subjected to the action of the smaller needles.

The only type of needle crushers built in America is shown in Fig. 135. A comparative test made with this crusher against a roll crusher gave the following results:

When mine run was crushed with a roll crusher, about 30 per cent. of the shipments from the washery were No. 1 Nut (over 1½ in.) while shipments from the washery where the needle

crusher was used were about 45 per cent. of No. 1 Nut; an increase of 15 per cent. in the quantity of the highest priced prod-

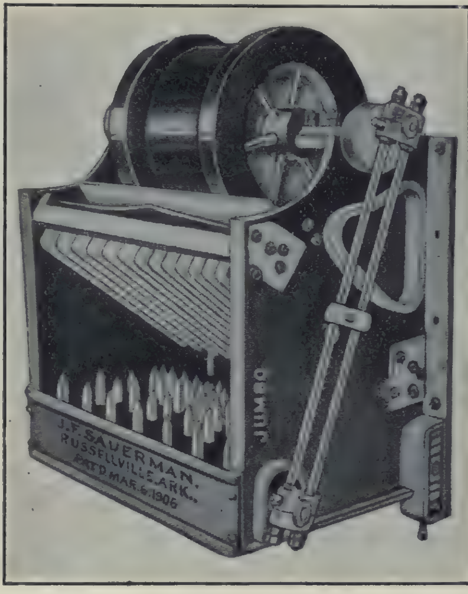


Fig. 135. Sauerman Needle Crusher

uct. Of this 15 per cent., 10 per cent. came from the decrease in No. 4 and No. 5 and the remaining 5 per cent. came from the

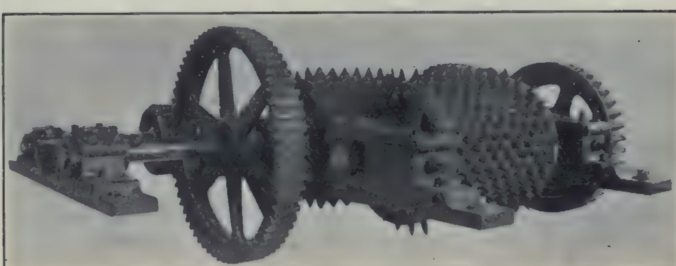


Fig. 136. Toothed Roll Crusher

decrease in quantity of No. 2 and No. 3. The tests were made under the same conditions and with coal from the same bed.

Roll crushers can be divided in cracking rolls that take the

largest lumps coming from the mine and crush them to about 3 in., and crushing or finishing rolls which reduce the 3 in. coal to any desired size, usually ¾ in.

Fig. 136 shows the photograph of a pair of cracking rolls with

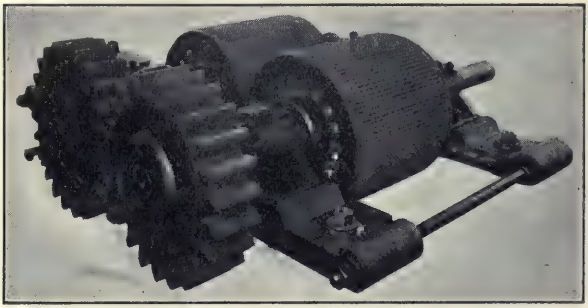


Fig. 137. Crusher with Rolls for Fine Crushing

manganese steel teeth cast solid with the shell. Fig. 137 shows a pair of finishing rolls. In both of the above illustrations the housing over the rolls has been removed.

Fig. 138 shows a complete set of crushing rolls with housings

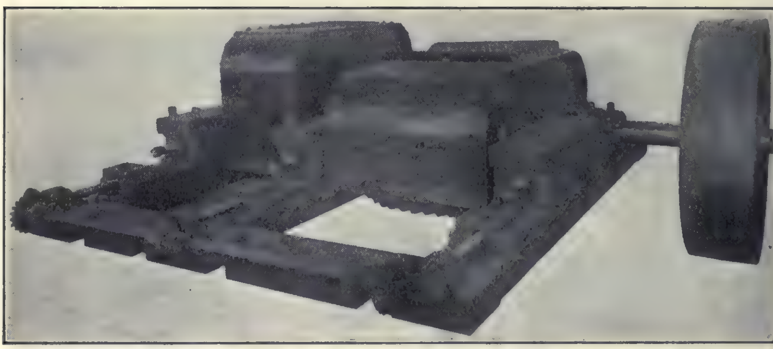


Fig. 138. Crushing Rolls with Housing Over Rolls and Gears

in place as well as over the gear wheels, as built by the Vulcan Iron Works.

The following table taken from *Coal Age* (Vol. 15, No. 14, 1919) gives results of tests made with roll crushers:

RECORD OF TESTS MADE WITH SMOOTH AND CORRUGATED ROLLS AT COMMERCIAL COAL-PREPARING PLANTS

Line	Size of Rolls: Diameter, In.	Size of Rolls: Length, In.	Surface of Rolls	Rolls Set Apart, In.	Peripheral Speed, Ft. per Minute: Fast Roll, Ft.	Peripheral Speed, Ft. per Minute: Slow Roll, Ft.	Kind of Coal	Approximate Size of Coal Fed to Rolls	Moisture, per cent.	Feed to Rolls Net Tons per Hour	Fineness of Cracked Coal: Through ⅛ in. Round Holes, per cent.	Fineness of Cracked Coal: Through ¼ in. Round Holes, per cent.	Fineness of Cracked Coal: Through ⅜ in. Round Holes, per cent.	Actual Horsepower to Crack Coal: Hp.-hr. per Ton of Coal	Actual Horsepower to Crack Coal: Hp. Net Average,
1	30	60	Smooth	⅛	1500	1050	Soft and friable	1¼ in. cubes to dust	2.10	100	75.10	97.50	99.20	0.49	49.0
2	30	60	Smooth	⅛	1500	1050	Hard and tough	1¼ in. cubes to dust	1.60	100	70.00	95.50	98.25	0.52	52.0
3	30	60	Smooth	1/16	1500	1050	Soft and friable	1¼ in. cubes to dust	1.85	80	86.00	98.25	100.00	0.63	51.0
4	30	60	Smooth	1/16	1500	1050	Hard and tough	1¼ in. cubes to dust	1.55	80	82.50	97.00	99.00	0.72	58.0
5	30	60	Corrugated	⅛	1500	1050	Hard and tough	1¼ in. cubes to dust	1.50	110	54.20	78.00	96.00	0.47	51.7
6	30	60	One smooth, one corrugated ...	⅛	1500	1050	Hard and tough	1¼ in. cubes to dust	1.60	105	65.60	87.10	97.50	0.50	53.0
7	42	60	Smooth	⅛	1500	1050	Soft and friable	1¼ in. cubes to dust	2.00	110	77.40	98.75	99.40	0.51	56.0
8	42	60	Smooth	⅛	1500	1050	Hard and tough	1¼ in. cubes to dust	1.65	110	74.20	97.50	99.10	0.54	60.0
9	42	60	Smooth	1/16	1500	1050	Soft and friable	1¼ in. cubes to dust	1.95	90	87.25	98.50	100.00	0.65	59.6
10	42	60	Smooth	1/16	1500	1050	Hard and tough	1¼ in. cubes to dust	1.75	90	85.00	97.00	99.70	0.75	68.5
11	42	60	Corrugated	⅛	1500	1050	Hard and tough	1¼ in. cubes to dust	1.60	121	56.80	80.20	97.50	0.47	57.4
12	42	60	One smooth, one corrugated ...	⅛	1500	1050	Hard and tough	1¼ in. cubes to dust	1.75	116	67.15	88.40	98.30	0.52	60.3

NOTES—Coal designated as soft and friable is Pocahontas coal. Coal designated as hard and tough is Pittsburgh gas coal. In each case the run-of-mine coal had been first sized by a Bradford coal breaker with 1¼-in. square perforations. The tonnage feed per hour is the maximum, with the designated diameter, length, surface, speed and distance rolls set apart. Speed of rolls great as permissible, without choking by the refusal of rolls to nip the largest pieces of coal. Rolls designated as corrugated have three corrugations to one inch, 3/16 in. deep.

TABLE 38

Rolls and hammer mills are the two distinct types[1] of machines extensively used for preparing coal for coking. Since it is possible to purchase either type of machine in almost any size and with the assurance that the design and construction are adequate for the work intended, the choice of type can be made strictly on the basis of suitability and economy.

There are certain advantages and disadvantages that are inherent in each type of machine, and these are generally well recognized. Of greater importance, and less generally appreciated, are the characteristics of each machine for a particular size and service.

Hammer mills pound and force the coal through perforations or longitudinally placed bars, the size and spacing determining the size of the largest pieces of the coal. Rolls crack the coal by compression and no interfering impediment obstructs its free passage from the machine after passing between the rolls, the distance apart the rolls are set determining the size of the largest pieces of the coal. The difference in principle of reduction evidently results in a considerable saving of power, in favor of rolls, that is worthy of consideration in making a choice of types on the basis of economy of operation and repair. Cracking the coal by compression in place of pounding and forcing it through a certain size of hole, results in a more uniform and better product for the effective operation of the succeeding cleaning method. The pounding and forcing action creates an excessive amount of fines and dust from both the impurities and the coal, which increases the difficulties involved in any cleaning method on a commercial scale or of separating the worthless matter from the valuable coal. It also adds to the difficulties of clarifying the wash water of refuse.

Since rolls act on the principle of cracking by compression and since, when they are set to crack the coal to any particular size, the particles smaller than that size can tumble through without being further reduced, rolls yield a smaller percentage of fines and dust and a more uniform finished product for the final cleaning or charging than any other type of coal-reduction machine. Rolls will crack wet coal as satisfactorily as when the

[1] "Rolls for the Preparation of Coking Coals." *Coal Age* (Vol. 15, No. 14, 1919).

coal is dry without increase in the absorption of power and without choking. Approximately 25 per cent. less power is required with rolls than with any other type of reduction machine to reduce like coal to the same degree of fineness. The upkeep and depreciation per ton of coal handled is barely noticeable owing to the few parts subjected to wear and tear. In case of choking, rolls can be relieved promptly without derangement of the covering. They are practically dustless and operate at a comparatively slow speed, have a large capacity per square foot of working surface and a minimum of skill and attendance is required. Instant and rigid adjustments may be secured in the space between the rolls; automatic adjustments for instantly relieving the rolls in case tough foreign matter is mixed with the feed may be employed as well as magnetic attachment for the removal from the feed of nails, nuts, mining-machine cutters and the like. A positive automatic feeding device to prevent overloading may be employed.

Rolls are comparatively reasonable in price and cost of installation. The relation between the maximum size of coal fed to rolls, the speed at which they revolve, the diameter and the space between them determine the angle of nip. With a spacing of 1/16 in. in the clear, and a peripheral speed of about 1,500 ft. per minute, the relation between the diameter of rolls and maximum size of individual pieces of coal is as follows:

Diameter of rolls 24 in. for	3/4 in. cubical form of lumps and less
Diameter of rolls 30 in. for	1 1/4 in. cubical form of lumps and less
Diameter of rolls 36 in. for	1 3/4 in. cubical form of lumps and less
Diameter of rolls 42 in. for	2 1/4 in. cubical form of lumps and less
Diameter of rolls 48 in. for	3 in. cubical form of lumps and less

TABLE 39

In discussing this question of crushing under different conditions there are four factors to be considered: (a) Compressive strength of material; (b) extent of crushing desirable; (c) work or power required for crushing; (d) comparison of various machines.

There are four ways that force may act in crushing coal or other material: (1) By direct pressure as between rolls where there is a strong force acting at low velocity; (2) by a blow on an anvil, as in stamps, where there is a medium force acting at a

moderate velocity; (3) by a blow in space, as in the hammer mill or Carr disintegrator, where there is a weak force acting at high velocity; (4) by grinding, as in the amalgamating pan. In the first three cases the force acts perpendicularly to the surface to produce rupture by compression; in the last case it acts obliquely, producing rupture by compression combined with shearing.

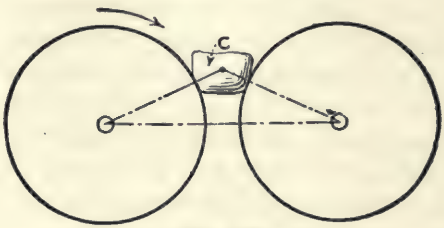


Fig. 139

Crushing rolls act upon the lump *C*, Fig. 139, on the principle of the toggle joint. The revolving rolls being held in position in their journals, act radially upon the lump, gradually drawing it toward the narrowest space between them and finally breaking it by virtue of a compressive force superior to the breaking strength of the lump. The lump is therefore broken by compression.

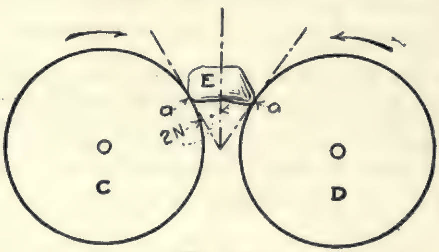


Fig. 140

The spaces between rolls vary from rolls close together up to ½ in. apart. The relation between the diameter of lump fed to rolls and the space between them, that is to say the amount of reduction, is highly important if rolls are to do their best work.

If the rolls *CD* (Fig. 140) be fed with a lump of coal *E*, the tangent to the rolls at *AA*, the point of contact with the lump, meet below, forming an angle $2N$, the half of which N is called

the angle of nip. This angle may have values from 0 deg., where the space between rolls is as large as the feed lump, increasing until the angle is so large that the rolls cannot nip the fragments. This angle of nip in any case will depend for its value upon the diameter of the rolls, the diameter of the lump fed and the distance in the clear at which the rolls are set. It is affected by the following factors: It is diminished by increasing the diameter of the rolls, by increasing the space (clear distance) between the rolls, and by diminishing the size of the lumps fed to the rolls.

A comparison of Figs. 141 and 143 shows that large rolls, acting on a given size of lump, have smaller angles of nip than

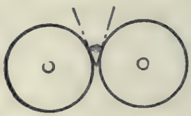


Fig. 141

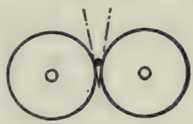


Fig. 142

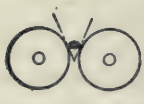


Fig. 143

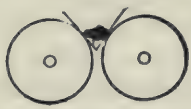


Fig. 144

have small rolls. Figs. 141 and 142 show that larger spaces give smaller angles of nip. Figs. 141 and 144 show that smaller lumps give smaller angles of nip.

There are two values of this angle of nip which are of special interest; namely, when its value equals the angle of friction, and the rolls do no work; and when its value becomes the practical angle of nip, at which rolls will work satisfactorily. The angle N, Fig. 145, becomes the angle of friction when it is of such a value that a sphere fed to the rolls will just slip upon the points of contact and therefore fail to be crushed.

All relations between size of feed, space between rolls, radius of rolls and angle of nip can be expressed by a simple formula, which is derived as follows (see Fig. 145): If $b =$ radius of sphere to be crushed, $a = \frac{1}{2}$ space between rolls, $N =$ angle of nip and $r =$ radius of roll $= \frac{1}{2}$ diameter, then

$$\frac{r + a}{r + b} = cosine\ N$$

Theoretically, increase of speed, provided the reduction in size is sufficiently slight, can be made to almost any limit; but practically, high speed with any considerable reduction will give trouble, owing to the refusal of the rolls to nip or take hold of the lumps. These fly back until a dangerous amount collects and then the rolls choke. This may be explained as follows: A lump of coal falling under the influence of gravity from heights of 6, 12, 18 and 24 in. will have final velocities of 340, 481, 589

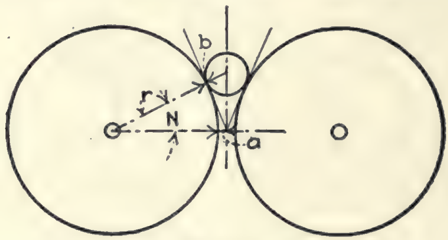


Fig. 145

and 681 ft. per minute respectively. Now, if the rolls are revolving at 900 ft. per minute peripheral speed, then a certain part of the friction must be used to accelerate the lump of coal to this speed before it will be nipped. This amount will be greater or less according as the peripheral speed of the roll exceeds the velocity of the particle by much or little. The use of a part of the friction for the purpose of accelerating the particle does not in itself prevent the particle from being finally nipped, but merely delays the nipping action. It is this delay during the time necessary for accelerating the particle which prevents the nipping, for until accelerated to the speed of the rolls the particle is necessarily slipping and this slipping smooths the surface to a certain extent which causes the coefficient of friction to be reduced and prevents the particle from going through.

Rolls of large diameter apparently possess three advantages over those of small diameter: (1) The increased surface allows more feed to be crushed with a single pair of rolls, but the gain is not important unless the renewals in the case of the smaller

rolls are so frequent as to cause serious delay and added cost. The wear of rolls per ton crushed would probably be the same in both cases. (2) The larger rolls can make a greater reduction in size of lump, the angle of nip and the peripheral speed being the same in both cases. (3) Larger rolls have a greater capacity than smaller ones, the reduction being the same, since they can be run at a higher rate of speed on account of their more advantageous angle of nip. In case both the reduction and peripheral speed are the same for the large and small rolls, the large rolls will make the reduction more gradually and hence with less shock.

Some authorities advocate running one of the rolls slightly faster than the other in order to prevent the exact mating of the rolls with a consequent possible unevenness of wear resulting therefrom. This is especially true with geared rolls. The use of any considerable differentiation of this kind to produce grinding, with a view of increasing the crushing power, has been proved fallacious on hard brittle materials, since such an action requires increased power without corresponding benefit. In regard to soft and friable material, however, the case is different. The material which is soft, when crushed by smooth rolls running at equal speeds forms ribbons or pancakes, while a differential adjustment tears the material apart, completely overcoming this difficulty.

The Bradford Breaker. The Bradford breaker [1] was patented in 1873 by Hezekiah Bradford, of Reading, Penn. He had in view the breaking, sizing and preliminary cleaning of anthracite coal, without causing the excessive quantity of fines produced by the toothed rolls then in general use. However, it did not accomplish, on a commercial scale, what was proposed on account of the nature of anthracite coal and intermixed impurities. Its first employment in the preparation of coking coal is recorded in 1891, when the St. Bernard Coal and Coke Co. (Earlington, Ky.), the St. Clair Coal and Coke Co. (Bradenville, Penn.), and the Loyalhanna Coal and Coke Co. (Loyalhanna, Penn.) used it for the breaking, sizing and preliminary cleaning of coal.

At this time there are approximately 300 Bradford breakers

[1] "Bradford Coal Breaker and Preliminary Mechanical Cleaner." *Coal Age* (Vol. 15, No. 8, 1919).

in active operation in the United States; about 75 per cent. of these are in connection with byproduct and beehive coke-oven plants, the others for preparing bituminous coal for producer, stoker and special use.

The present construction and operation of the breaker differ materially from the first installation and early practice, the improvements being important and of value; while the original machine demonstrated the merit of the principles involved, yet its mechanical operation or action was not satisfactory. The principle is to break the pure coal by concussion and screen it out through the encircling perforated plates, while the impurities, mingling with the mined coal, are generally too tough to be broken by this force of concussion and therefore pass over the perforations and out at the end of the machine to a separate chute. The breaker consists of a large diameter cylinder covered with perforated steel plates; it is intended to revolve slowly.

The machine is useful for preparing coal for further crushing and cleaning (Fig. 146); however, if the coal, after passing through the perforations of the breaker, is considered clean enough for coking, then a pulverizing mill is substituted for the rolls, so that impurities intermixed with the coal will be powdered and the whole product be of the same degree of fineness. The function of the Bradford screen is to break the pure coal to a size that will sift through the perforations, without breaking much of the bony coal, slate, rock and pyrites intermixed with the coal; further, that these impurities may be discharged separately. It also automatically discards foreign matter larger than the perforations, like car and rail irons, wooden sprags, and so on, that would be injurious later to the rolls or pulverizers. Bins are provided which act as reservoirs to insure a uniform supply of coal to the preparation plant and as storage in case of irregular delivery of coal from the mines.

The mechanical feeder not only regulates the tonnage delivered to the screens but also tends to balance the loading of elevators and conveyors handling the prepared coal. The shaking screen separates the coal into sizes suitable for further treatment; it relieves the breaker of handling coal already of the proper size for the rolls, and it also bypasses around the rolls the coal that is fine enough for use. The duty of the magnetic separator is to remove

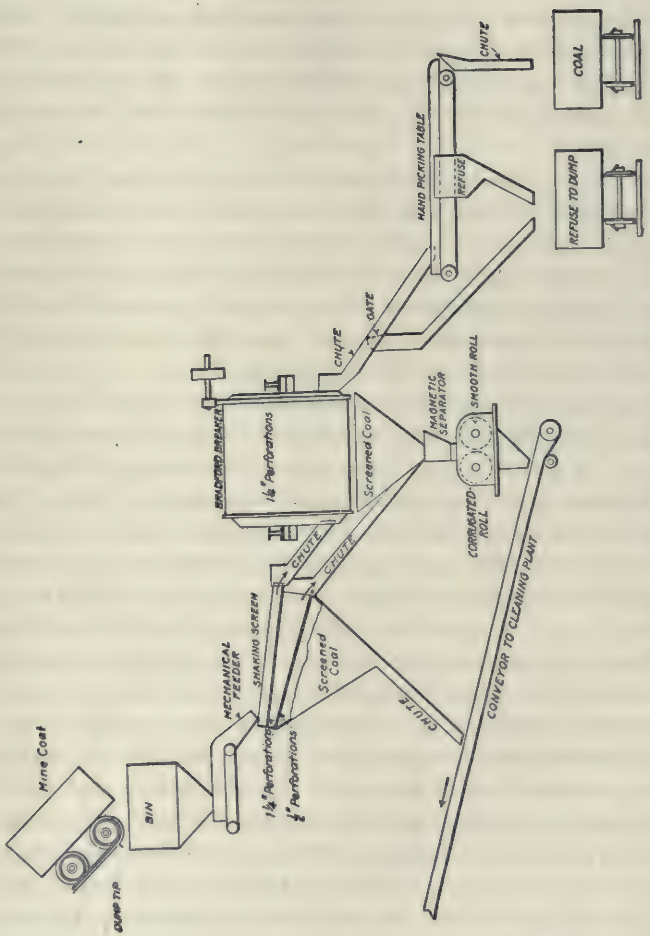


Fig. 146. Bradford Breaker Installation

pieces of iron, like bolts, nuts, rivets and mining machine parts, that drop through the perforations, thus preventing serious injury to the rolls or the pulverizer.

The advantages of rolls are that they break the coal so as to release more or less of the impurities of a laminated nature, without pulverization; crushing, grinding, pounding, bruising and pulverizing all tend to create powder or dust of both the coal and the impurities; this latter is quite an unfavorable condition and hinders success in either a dry or wet method of coal preparation.

The hand picking table is of use when the coal bed contains bands of bony or high ash coal; the breaker is then adjusted and operated to discard as much as possible of this inferior coal, together with the other bulky impurities, as these coals inferior for coking purposes contain much fuel value for steam and domestic use; the fuel values are separated from real impurities by hand, while being conveyed on the picking table.

In the general operation of the Bradford breaker run-of-mine coal is automatically fed into one end of the cylinder (while revolving), is picked up by longitudinal shelves and dropped, falling on cast steel "shatter fingers" attached to the perforated plates; the coal is shattered by concussion (see Fig. 147), and the pieces that are small enough sift through the perforations; the shelves following pick up the large pieces, which are again thrown down. The coal in falling from the shelf has not only the force derived from its own gravity, but receives considerable additional force from the momentum of the cylinder. The coal does not fall upon coal in the lower part of the cylinder, but upon the shatter fingers and perforated plates, because the coal is constantly carried toward and upon the rising side and shelf. In rolling and tumbling around in the cylinder any remaining pieces of pure coal attached to the impurities break away and sift through the perforations. The cast steel shatter fingers not only aid in breaking the coal, but are so set on the inside of the cylinder as to form a spiral, which can be adjusted either to rapidly advance the body of coal to the opposite end or to retard its progress.

Fastened in the opposite head of the cylinder from which the coal enters are refuse removers (wing-like in form) which auto-

matically discard any impurities or other matter larger than the perforations into a chute. The coal sifting through the perforations on the revolving screen is collected underneath the cylinder and is conducted by a chute to the desired point for shipment or treatment.

The Bradford breaker is adjusted and detail parts are designed to suit the physical characteristics of the coal to be treated, the requirements of the market and the general conditions and circumstances of each individual case. The capacity and quality of work is affected by the diameter and length of the screen, the size of perforations, speed of rotation, spirality of the shatter fingers and the moisture content and physical properties of the pure coal and impurities. The difficulty with coal, of course, is that it is not a manufactured article, in the making of which certain ingredients are used under fixed conditions with results always approximately the same; on the other hand, it is a natural product varying greatly in quality, often even in the same seam, and it must be admitted that any attempt to standardize a coal-preparing machine or method under these circumstances would prove an almost impossible task.

Coal always contains a certain amount of inorganic matter or ash which is intrinsically part of the coal. The question as to whether one could clean a given coal materially or not depends largely—essentially, in fact—on the way in which that inorganic matter was distributed through the coal.

The rated capacity of a breaker is the number of tons that can be broken sufficiently to sift through certain size perforations in a given time (usually one hour), and simultaneously to discharge separately from the broken coal the impurities not broken by the action of the breaker. Breakers now in operation vary in capacity from 30 tons an hour (fitted with ½ in. perforations and handling tough coal) to 400 tons an hour (fitted with 3 in. perforations and handling friable coal).

The quality of work done by a breaker is shown by the quantity of pure coal broken fine enough to sift through its perforations, without at the same time breaking the impurities (that are more or less intermixed with the coal) so small as to permit of their passing through the perforations, the impurities being discharged separately from the coal. When making comparisons

of different installations regarding the capacity and quality of work done by breakers, it must be kept in mind that many coals that break cubical in shape (or nearly so) go through a screen quite fast, but coals that break in elongated pieces do not screen nearly as fast as the cubical pieces. Also, when comparing laboratory tests with commercial results, it should be remembered that the laboratory tests show the best theoretical results attainable by working in the ways described—such results represent the ideal to be attained by commercial methods.

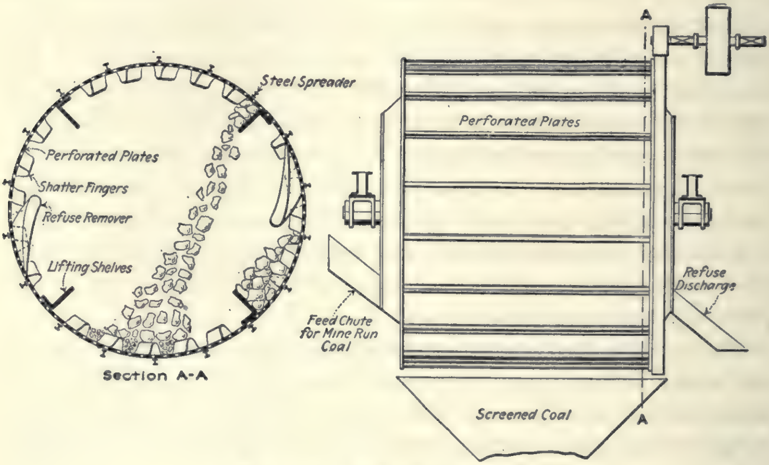


Fig. 147. Bradford Breaker

Structurally a Bradford breaker is a circular screen of perforated plates bolted to an iron framework. Cast-iron spiders, or rings, carry this framework, and the rings are rigidly connected to a central longitudinal revolving shaft. The screen is inclosed by a casing that confines dust and prevents its circulation throughout the tipple. This casing protects workmen against accident and yet suitable doors are provided so that necessary inspection of the screen and its operation can be made. All portions of the screen are constructed so as to permit of ready renewal or adjustment of parts; should the character of the coal being prepared change, or different marked conditions develop, then parts either can be replaced or adjusted without serious disturbance to the plant. The perforated screen plates are made

of extra heavy steel cut to a standard size so as to fit any breaker of the same diameter. These plates can have one size perforations at one end of the screen and larger perforations at the other end; this arrangement permits of two sizes of coal being made. Suitable provision in the chute to carry off the screened coal keeps the two sizes separate.

The cast-iron lifting shelves in the screen are made of a width, length and angle proportioned to the work desired and the speed of rotation, so that the coal may slide from the shelves at the proper height to fall upon the required part of the inner side of the screen; the shelves are made interchangeable and can be replaced or their position changed without affecting other parts of the breaker. Usually four shelves are equally spaced on the inner side of the screen, although from one to six shelves may be used, depending on the coal handled.

The cast-iron refuse removers in the screen automatically discharge the impurities; generally two are used for rapid discharge. However, if a portion of the coal is more or less tough, so that it requires further tumbling to break up the coal, then only one remover is used. In selecting a breaker it will be well to confer with those familiar with the principles involved, its construction and operation; also, one should be thoroughly versed as to the nature of the coal to be handled and the separation of impurities desired. Each variety of coal requires special treatment in the breaker, which can only be accomplished by properly proportioning the parts during construction. The method of operation should be determined after a careful study of the physical properties of the coal. A knowledge of the business end of the proposition is essential, as that often makes all the difference between success and failure. It is rather remarkable that in some districts collieries which are in close proximity to each other sometimes differ in a radical manner in their treatment of coal from the same bed. In designing a plant it is not always safe to rely on a neighbor's experience, or even on one's own experience elsewhere. This uncertainty is often most puzzling and perplexing, but perhaps it is the most interesting of the various problems in connection with mining engineering.

Details of No. 11 Test. Below is given a record of five tests made with run-of-mine coking coal from five mines working the

Record of Tests with Run-of-Mine Coking Coal

Mine	Run-of-Mine Coal Per Cent.	Run-of-Mine Coal Per Cent. Ash	Screened Coal Per Cent.	Screened Coal Per Cent. Ash in Screened Coal	Breaker Refuse Per Cent.	Breaker Refuse Per Cent. Ash in Refuse
1	100	18.70	87.71	14.10	12.29	51.30
2	100	15.45	86.43	10.84	13.57	44.65
3	100	16.25	85.81	13.00	14.19	35.70
4	100	15.80	90.17	13.30	9.83	38.40
5	100	18.22	79.85	13.72	20.15	36.00
Average,	100	16.88	86.00	13.00	14.00	41.21

Table 40

same coal seam with a Bradford coal breaker 9 ft. in diameter and 11 ft. long. Perforations ½-in. square, peripheral speed 425 ft. per min. Feed 60 net tons per hour. The coal was quite soft and dry, the rock and bony tough and the slate brittle.

The foregoing tests show that discarding 14 per cent. of the impurities in the run-of-mine coal larger than the ½-in. perforations reduced the ash content from 16.88 per cent. to 13 per cent., which was not acceptable for furnace coke. The screened coal from the five tests was washed, with the results shown below:

Kind	Per Cent. Run-of-Mine Coal	Per Cent. of Kind	Per Cent. Ash
Breaker screened coal...........	86.00	100.00	13.00
Washed coal	73.48	85.44	9.13
Washer refuse	12.52	14.56	35.71

The foregoing results indicate that to reduce the ash content from 16.88 per cent. in the run-of-mine coal to 9.13 per cent. in the washed coal it was necessary to discard a total of 26.52 per cent. of the run-of-mine coal as breaker and washer refuse.

When only 3-in. screenings are to be crushed, one set of crushing rolls will be sufficient, but if run-of-mine is to be crushed for coking coal, it is advisable to crush in two stages. (1) From run-of-mine to 3 in. in a crusher having toothed rolls and (2) from 3 in. to the desired size in a crusher having either corrugated rolls or rolls with waffle-iron teeth.

In either case a magnetic separator ought to be placed ahead of the first crusher to catch all tramp iron and a feeder to reg-

ulate the stream of coal coming to the machine. It would also be a good investment to install ahead of the crusher a small equalizing bin, as the coal comes from the mine in pit car lots at intervals. This will reduce the power required to drive the crushers decidedly. It is also important to install screens in front of each crusher, that will by-pass all coal finer than the crusher is set to make. These screens must be of ample dimensions to secure the screening out of all the fine coal. Roll grizzlies—if long enough—will answer the purpose if the coal to be crushed is dry. With wet coal the grizzlies clog up and act only as conveyors.

If close crushing is required and oversize objectionable, a sizing screen ought to be installed after the final crushers. The oversize from this screen must be returned to the crusher and remains in a close circuit until reduced to the proper size to pass through the screen.

CHAPTER XXVII

CRUSHING AND RE-WASHING OF THE MIDDLE-PRODUCTS

When retreating middle products the materials to be crushed consist of washed but intergrown coal from $\frac{5}{16}$ in. to 3 in. in size. The purpose of crushing is to break up the intergrown particles in such a way that the slate or bone adhering to or disseminated throughout the coal shall be mechanically separated from it. This will give a homogeneous mass of material suitable for rewashing.

Two considerations must be taken into account. The character of the middle product influences, at least in a theoretical way, the crushing process. The most suitable method would be, without doubt, to spall off the slate and bone without crushing them. This would make the subsequent water clarification and sludge recovery much easier. But the foregoing procedure would only be possible if the impurities are attached to the coal as shown in Fig. 148. This condition occurs only in solid coal,

Fig. 148

where the impurities are to be found at the cleavage line between the bed of coal and the roof or the bottom. In most cases, however, we must consider impurities, which are more or less disseminated throughout the coal mass, as shown in Fig. 149. In this case a crushing of the impurities cannot be avoided. (2) In every case the degree of crushing—that, is, the difference between the size of the material before and after crushing—must be made as small as possible. The crusher giving the greatest yield with the smallest amount of sludge is the one most suit-

able, because this permits the most perfect separation. Whether, in each separate case, the yield or the amount of sludge should be considered more important depends on the one hand upon the difficulty of water clarification and on the other hand upon the value of the fine coal.

The crushing plant ought to be located between the primary and rewash jigs. This will necessitate the installation of an elevator, because all the jigs should be located upon one platform at the same level.

The crushing of the middle products can be accomplished

Fig. 149

either with roll crushers, gyratory crushers or disintegrators. Roll crushers can have either smooth or slightly corrugated rolls. Such crushers will permit the free passage of flat pieces of slate, which affords a decided advantage over all other types. For crushing down to 3/16-in. size, roll crushers are well adapted. If the middle product should be crushed still finer, gyratory crushers or disintegrators are advisable. Gyratory crushers can be used down to 1/16 in. size, and for still finer crushing disintegrators should be employed.

CRUSHER DATA

Type	Crushing From	Crushing To	Capacity per Hour in Tons	Power Required
Roll crusher	3 in.	3/16 in.	6 to 60	3 to 50 h.p.
Gyratory crusher	3 in.	1/16 in.	1 to 12	2 to 20 h.p.
Disintegrators	3 in.	65 mesh	3 to 85	2 to 150 h.p.

TABLE 41

The process of rewashing does not differ materially from the process used in primary washing. The regulation of the rewash process depends upon the purpose for which the resulting products will be used. If, according to the character of the

middle product, only boiler-house coal can be made, close washing is not necessary and the rewashing should be carried on in such a way that the resulting refuse will be as free from good coal as possible. If, however, the middle product is of such a nature that the pure coal contained therein is good enough to be mixed with the primary washed coal, the middle product should be washed very closely. In some cases it would be more economical to rewash for boiler-house coal only, even though the product of the rewash jigs could be made clean enough to be mixed with the primary washed coal, on account of the great loss of good fuel in the refuse, imposed by trying to get a perfectly clean washed product.

CHAPTER XXVIII

DE-WATERING AND STORAGE OF FINE COAL

Washed coal must be freed from adhering moisture before it can be shipped to market. Coal larger than ½ in. can be dewatered easily by simply passing it over draining screens, but the dewatering of finer sizes is a different problem and the methods used at present do not give entirely satisfactory results. We should not overlook therefore any efforts for further development and improvement in the process of dewatering the fine coal.

Before we can discuss intelligently the methods used at present, we must first determine the purpose of the dewatering process and the scope of the demands made by it upon the apparatus used. The final purpose of dewatering is to produce a coal of the highest possible value. This will permit us to predetermine in each separate case the most economical degree to which the dewatering should be carried. Some typical cases are as follows:

Coking Coal. A moisture content of from 4 to 6 per cent. is the most suitable for the coking process in retort ovens when utilizing the by-products. Therefore the coal, if the character and size will permit, must be dewatered to this extent. If this is not possible, other means must be employed to help out. Dry-screened dust may be mixed in or even dry-screened fine coal. The amount of the unwashed coal which can be thus mixed in depends upon the percentage of ash it contains.

Fuel Coal. The degree of dewatering of fine coal depends upon the demands of the consumer, but the moisture should not exceed 10 per cent. Mixing in of dry unwashed fines will also be of some benefit, but the recrushing of coarse coal for this purpose should be avoided ordinarily on account of the greater value of the coarser sizes.

The following may be considered, taking into account the diffi-

culties of dewatering and the rapid increase of these difficulties with any decrease of the moisture in the final product. As much as the conditions permit, the drying of the fine coal should be aided by the mixing in of dry raw coal.

In most cases greatest possible dryness of the coal is required. The requirements of this dryness should be established beforehand by a guaranty in regard to the permissible upper limits of moisture in the final product, so that the washery as well as the consumer may have fixed data to go by.

Simplicity of installation demands the smallest possible space, low power consumption and small cost of installation and operation. The dewatering of the fine coal, appearing at first sight to be easy, thus becomes a difficult problem made more difficult by the inclination of the fine coal to pack together in dense cakes containing a high amount of water.

The continuous stream of coal coming from the mine does not allow, except at high cost, the devoting of much time to any one separate stage of its preparation. One process must follow another without appreciable intervals or interruptions. Even in the storage bins the coal does not remain for any length of time. It must be loaded out continuously. A coal washery knows only the following alternative—few swiftly operating pieces of apparatus or a great number of slower-working machines. For all previously enumerated apparatus the principle of quick operation is easily accomplished; the treatment of fine coal offers serious difficulties which still remain to be solved satisfactorily.

The methods to be employed for drying coal must be adapted to the character of the material. This requirement demands especial consideration. It is impossible to prefer one method above all others at first sight. The character of the fine coal from different mines shows many variations. With a hard, not easily shattered slate the fine coal, and especially the sludge, are innocuous. The dewatering is comparatively easy and can be, at least partly, combined with the water clarification process. But if the slate, or what is even worse, the slate and coal are disposed to produce a microscopically fine pulp held in suspension in the water, the process of dewatering must be carried on in an entirely different manner. The separation of the fine coal from

the pulp must be accomplished in the early stages of the process if it is to be carried out successfully.

Methods of Drying. Considering the requirements set forth we have the following methods for drying in use at the present time: (1) Dewatering in bins or pits; (2) dewatering on slowly moving conveyors; (3) centrifugal dryers; (4) filters (for sludge only).

De-watering Pits.[1] The attractive features of dewatering pits are: (1) A drained washed coal containing 8 to 9 per cent. moisture; (2) a filtered water free from sediment, for recirculation; (3) no escape of dirty water (to pollute private and public streams) except that small amount evaporating and adhering as external moisture to the coal; (4) a rapid filtration of the water so as to gain a brimful pit of coal, without shifting the stream of water and coal from the washing machines; (5) uniformity of the drained mass of coal, in regard to fine and coarse sizes, sludge and pieces of various characteristics being evenly distributed so that a homogeneous coking coal may be gathered; (6) no mechanical power necessary to aid or hasten the dewatering of the coal; (7) permanent construction with only a minimum maintenance expense; (8) an economically operated apparatus for removing the drained coal.

The principle involved in the drainage of coal in a pit is that water moves gradually in a wavering descending motion through a mass of minute particles at rest, and is clarified during this movement. The dewatering capacity of a pit depends upon the relation between the number of square feet of filtering surface to the quantity of water delivered in a given time and the fineness of the coal.

Tests made at five coal washeries using dewatering pits indicate that the average filtering capacity of a pit is 32 gal. of water per hour for each square foot of filtering surface, when dewatering coal in sizes ranging from ½-in. cubes to dust, and the pit will be filled brimful of coal without temporary cessation to prevent water overflowing the pit walls. Most careful moisture determinations were also made of the drained washed coal at different times as gathered from the pits for coking after various

[1] "Dewatering Pits for Washed Coal," *Coal Age* (Vol. 14, No. 24, 1918).

hours of drainage, with the results shown below, the drained washed coal averaging in fineness ½-in. cubes to dust.

Pits 24 Ft. Deep	Average Moisture, per cent.	Maximum Moisture, per cent.	Minimum Moisture, per cent.
After 24 hours' drainage........	9.15	10.36	7.37
After 36 hours' drainage........	9.05	10.61	7.10
After 48 hours' drainage........	8.26	10.13	7.00
After 60 hours' drainage........	8.05	9.74	6.84
After 72 hours' drainage........	7.97	9.48	6.18
Pits 16 Ft. Deep			
After 12 hours' drainage........	10.05	12.96	8.16
After 24 hours' drainage........	8.46	9.07	8.06
After 36 hours' drainage........	8.39	8.60	8.03
After 48 hours' drainage........	7.90	8.31	7.76
After 60 hours' drainage........	7.65	8.00	6.85
After 72 hours' drainage........	7.60	7 79	6.90

TABLE 42

The pits are formed by rectangular concrete walls of a thickness suitable to withstand the pressure when the pits are filled with coal and water. The ultimate concrete bottom is laid slightly sloping toward centrally located drains which transfer the filtered water to a pump sump for repeated use. Above the ultimate bottom, leaving an intervening space of 4 in., a filtering platform is placed. This contains small V-shaped gaps for supporting the coal and allowing the passage of the dripping filtered water onto the concrete bottom. In practice the final 8 to 12 in. in depth of coal is not drawn off but remains on the filtering platform as a permanent filter bed. This bed should be stirred up frequently, say after each third filling of the pit, by the appliance provided on the traveling coal excavator, so as to present a more nearly perfect porous bed, in order that the filtering capacity of the pit may not become diminished.

The permanency of properly designed and constructed concrete pits is unquestioned. They do not deteriorate in usefulness or value by constant usage. The only renewal necessary is the replacement of the false bottom used as a filtering platform in two to four years, according to usage. This platform is built in sections of about 4 x 6 ft., so that one or more sections may be readily replaced when necessary.

The cleaned coal and black water from the washing machines

is delivered directly to the pits by means of extension gravity sluiceways swung over the top of the pit so that the latter will be uniformly filled with coal. The separation of the water from the coal require no machinery, attendance or supplies. To save the water draining from pits when the washing machines are not in operation, concrete reservoirs of sufficient capacity are provided with drains from the pits and to a pump sump, so that all water will be saved for recirculation when the washing machines are again operated. As there are no drains leading from any part of the drainage system to sewers or ditches, there is no chance to pollute streams with water holding impurities in solution or suspension.

There are no mechanical dewatering units between the washing machines and the drainage pits. The problem of sludge and dirty water disposal is thus entirely eliminated, as all fine coal and sludge is intermixed with the drained washed coal. This method of dewatering results in a great saving of water, power, labor and upkeep over the ordinary expensive dewatering methods employing centrifugal driers or perforated bucket elevators, with sludge tanks and a multiplicity of machinery. Whenever these are in use great fields of fine coal and sludge are visible with the accompanying pollution of near-by streams.

The fines to be dealt with consist of particles capable of passing through extremely fine meshes, the greater part of them being from ⅛ in. to 1/100 in. in diameter, or say, from 64 to 10,000 to the square inch.

In table 43 is shown the number of square feet of pit filtering surface necessary, when washing coal at the rate of 200 net tons

MOISTURE DETERMINATIONS AFTER VARIOUS HOURS OF DRAINAGE

Ratio of Water to 1 Ton of Coal	Various Quantities of Water Necessary to Wash 1 Net Ton of Crushed Raw Coal			Net Tons of Crushed Raw Coal Washed per Hour	Square Feet of Pit Filtering Surface Necessary
	In Cu. Ft.	In Gal.	In Lb.		
1	32	240	2,000	200	1,500
1½	48	360	3,000	200	2,250
2	64	480	4,000	200	3,000
2½	80	600	5,000	200	3,750
3	96	720	6,000	200	4,500
3½	112	840	7,000	200	5,250

TABLE 43

per hour, with jigs that require varying quantities of water in order to wash one net ton of raw crushed coal.

The ratio of water to that of coal is determined by the water requirements of the particular coal-washing machine under consideration. One washery handling 200 tons of coal per hour, adopting a specific form of washing machine, may need water in the proportion of 1½ to 1 of coal, requiring only 2250 sq. ft. of pit filtering surface; while another washery handling the same tonnage per hour using another form of washing machine may need water in the proportion of 3 to 1 of coal, necessitating 4500 sq. ft. of pit filtering surface.

When considering the adoption of dewatering pits, it is important to study the water requirements of coal-washing machines and to see that a machine requiring an extravagant quantity of water is not selected, since it would demand dewatering pits of extreme and excessive dimensions. As aforementioned, the series of tests made, relating to the filtering capacity of pits, demonstrated that the drainage capacity averaged 32 gal. of filtered water discharged per hour for each square foot of filtering surface, through coal ranging from ½-in. cubes to dust.

To ascertain the floor dimensions of a pit to hold, say, 1000 net tons of drained coal, or 40,000 cu. ft., weighing on a dry basis 50 lb. per cubic foot, assuming that water will enter the pit with the coal for five consecutive hours, the coal coming at the rate of 200 tons an hour, each ton requiring 360 gal. of water for washing, the water filtering away at the rate of 32 gal. per hour for each square foot of filtering surface, the formula is as follows:

Let

a = The number of gallons of water required to wash one ton of coal;

b = Tons of coal delivered to pit per hour;

c = Gallons of water filtering away per hour, per square foot of pit surface;

x = Square feet of pit surface required.

Then

$$\frac{ab}{c} = x.$$

Example—$a = 360$ gal. of water per ton of coal;
$b = 200$ tons of coal;
$c = 32$ gal. of water per hour per square foot of draining surface.

Then $360 \times 200 \div 32 = x$, or 2250 sq. ft. of pit floor surface required. This would be equivalent to a pit, say, 30 ft. wide by 75 ft. long.

The formula for determining the height of pit walls is as follows:

Let
$d =$ Square feet of pit surface required;
$e =$ Cubic feet of coal required;
$x =$ Height of walls in feet;

$$\frac{e}{d} = x.$$

Example—$d = 2250$ sq. ft. of pit floor surface;
$e = 40{,}000$ cu. ft. of coal.
$40{,}000 \div 2250 = x$, or 17 ft. 10 in. = the height of pit walls.

To offset the 8 in. to 12 in. in depth of coal used as a filter bed and the height of filter platform above the concrete floor, about 20 in. must be added to the height of walls, to acquire a working capacity of 1000 tons of coal. This will make a pit averaging, say, 30 ft. wide, 75 ft. long and 19 ft. high above the concrete floor.

A pit to drain coal from a washery using 720 gal. or double the quantity of water assumed above as being necessary to wash a ton of coal, would require a filtering surface of 4500 sq. ft. to receive the coal and water in five consecutive hours at the rate of 200 tons of coal per hour. This would mean a pit, say, 45 ft. wide, 100 ft. long and with a total depth of 10 feet 6 inches.

A pit this size would not be economical in ground space, construction or in handling the coal and water to and from it. Dewatering pits are not practical to operate in connection with washeries using an excessive quantity of water to wash a ton of coal.

The table showing moisture determinations after various

hours of drainage indicates that after 24 hr., additional drainage time does not reduce the moisture content of the coal materially, the water draining off rapidly; and with the exception of a few feet at the top, no benefits of air circulation are secured to aid in reducing the moisture. The coal is so closely packed by the water action that trenches formed by slides 30 in. wide and 4 to 6 ft. deep do not cave in.

The drained coal is gathered from the pits by a crane, having a vertical and horizontal motion. This is mounted on wheels and provided with numerous buckets for excavating and elevating the coal to a belt conveying system that discharges it into larry bins for use in coking. The crane spans the pits, and its movements are guided by rails fastened to the top of the longitudinal pit walls. The elevating capacity is from 400 tons per hour up.

Draining Bins. The dewatering of the fine coal is also accomplished to some degree in the commonly used storage bins. A storage of 48 hr. will reduce the moisture in the coal to from 10 to 12 per cent. In Europe draining bins are commonly employed and the draining off of the water is accelerated by the use of filter bodies made of expanded metal, which open up the densely packed mass of fine coal. The following results have been obtained with this type of bin:

Capacity of Washery in Tons per Hour	Contents of Bins in Tons	Number of Bins	Time Required Filling-Dewatering of One Bin in Hours		Capacity of All Bins in Tons per Hour	Degree of Moisture in the Dried Coal, per cent.
100	600–1200	4–12				
150	1200–2000	8–20	2–6	20–48	20–120	8–13
200	1400–3000	10–24				

TABLE 44

The disadvantages of draining bins are as follows: On account of the large surfaces the sludge settles out of the water, considerably delaying thereby the process of dewatering. On account of the lack of other drying apparatus, all sludge produced must be sluiced into the draining bins, there to be dewatered. This delays also the rapid draining off of the water. In emptying the bins, the coarse coal flows out more rapidly

than the fine coal and the sludge, which later clings to the walls. When the bins are emptied this sludge hangs to the walls for some time and drops off suddenly in large masses. This destroys that uniformity of the coal which is desirable for the coking process. The bins also require considerable space in all directions, and if the ground area at disposal is limited it will bring about a cramped or less desirable arrangement of the other apparatus.

To prevent dripping of the water on the floor below the bins, special gates are employed, which permit the water to flow out at one side where it can be carried away in pipes or open troughs. Fig. 150 shows the construction of such a gate. The

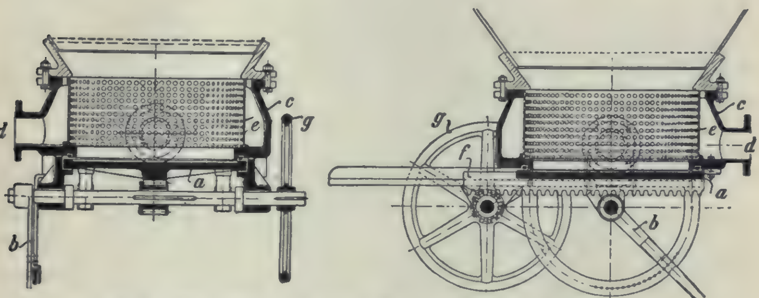


Fig. 150. Draining Gate Under Washed Coal Bins

slide is being pressed against the gate seat by the eccentric lever "b" and the water flows through the screen mantle "e" into a pipe "d." The gate can be opened by a rack and pinion "f" operated by a handwheel "g." This arrangement keeps the floor under the draining bins clean and dry and the outflowing water can be collected and returned to the system.

Draining conveyors work on quite a different principle. They dewater the fine coal on its way to the storage bins. No special dewatering device is necessary, and the conveying apparatus required in any case is adapted to dewatering the coal. Conveyors or elevators can be used for this purpose, depending upon the juxtaposition of the jigs to the storage bins. When these machines are employed the washed coal can be sluiced from the jigs directly to the conveyors. With elevators the coal must be sluiced into a settling tank out of which the elevators feed.

The drained-off water, carrying fine particles of coal in suspension, is sluiced into separate clearing tanks. Dewatering elevators must be built heavy, depending upon the character of the coal, the required capacity, and the distance over which the material must be conveyed. This is the more important since the speed of the conveyors must be slow in order to give the water time to drain off.

The following table gives some data on dewatering elevators and conveyors:

Type	Dimensions Width	Dimensions Length	Slope in Deg.	Speed, Feet per Minute	Capacity per hour in Tons	Power, Hp.	De-watered to per cent. Moisture
Dewatering conveyor	32 in.–13 ft.	50–130 ft.	0–40	1⅔–12	5–60	4–18	10–13
Dewatering elevator	20 in.– 6 ft.	50–130 ft.	40–65	3 –32	10–60	12–32	10–13

TABLE 45

Centrifugal Dryers. Centrifugal dryers, on account of their high speed, are restricted in regard to the dimension of the diameter of the revolving parts. To accomplish a satisfactory capacity only centrifugals with continuous feeds and discharge can be considered. At present only two types of these machines are in use. In one the dried coal is discharged continuously, being scraped off the screen plates by knives which rotate at a speed different from that of the screens. In the other type scrapers are not used and the coal is discharged from the screens through trapdoors which open and close intermittently.

The Elmore Continuous Centrifugal Dryer has many advantages over the so-called "batch" type of machine, chief among which are its greater capacity and its economy in power consumption. For certain substances, the increase in capacity is as much as twenty to one. The reduction in power consumption is due to the continuous rotation of the high speed parts, as opposed to the frequent stopping and starting of the "batch" type, which occurs many times within an hour. This increased capacity and saving in power results in large economy in the cost of the plant and its operation, as well as the saving in floor space, power, and labor required for operation.

Structure and Operation of Elmore Continuous Centrifugals. These machines are built in two types—Style A (Fig. 151) and Style B (Fig. 152) Fig. 153 shows a style A dryer with one screen segment removed, showing scrapers and distributing cone. Style A is driven from above and Style B from below. Style

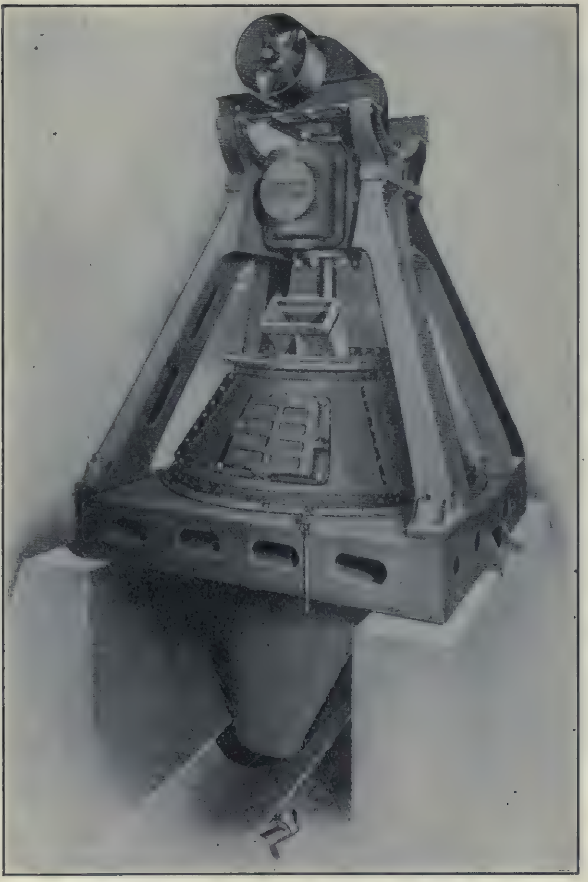


Fig. 151. Elmore Centrifugal Dryer. Style "A"

A can be driven by a counter-shaft, and rawhide bevel gear, as shown in Fig. 154, or by direct motor drive connected to the counter-shaft, or vertically mounted, as shown in Fig. 156. With direct motor drive, flexible couplings are used and speed

reducing gears of approved type are furnished to accommodate high speed motors.

The structure of the Style A machine is exceedingly rigid, the base alone weighing over 6000 lbs. Power is applied to the central shaft (3) which is carried with its weight and all that is attached to it, on the set of ball bearings (4) resting on top

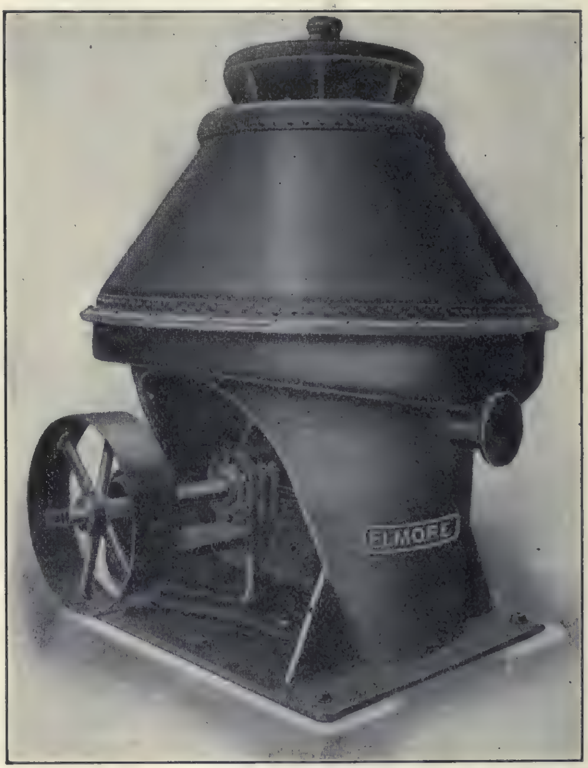


Fig. 152. Elmore Centrifugal Dryer. Style "B"

of the gear case (5). The main shaft (3) is guided only by the bearing (24) at its lower end and lubricated through pipe (25). At the lower end of shaft (3) is keyed a cast steel spider (22) and on its outer rim rests the truncated conical basket or screen frame (23) made in eight segments bolted together. To the inside of each segment is secured a suitable screen, the character of the perforations depending on the material to be treated.

The shaft, spider and screen frame (3, 22 and 23) have, therefore, a common support at the bearing (4) and a common rate of rotation. Near the upper end of the shaft (3) is keyed a steel cut gear (7) and by the four gears (7, 8, 9 and 10) power is transmitted to the hollow or quill shaft (12) which surrounds the main shaft (3). The gear (8) is keyed to the extended hub of the gear (9) which has a bronze bushing, and both revolve

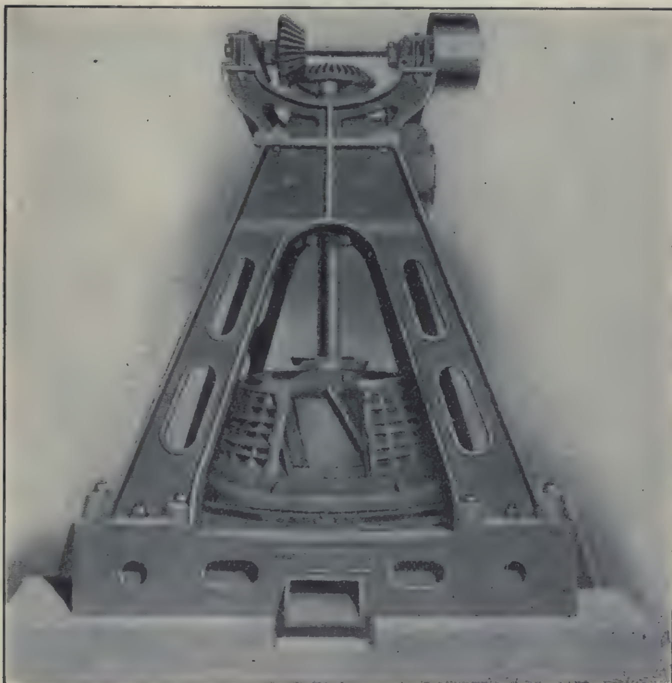


Fig. 153. Elmore Dryer with One Screen Segment Removed

on the stationary shaft (6) and their weight is carried by the ball bearing (11). Gear case (5) is divided on the center line of the shaft (6) and access to these gears is, therefore, very simple. Ample opportunity for inspection is afforded through the plates (34).

It will be noted that the quill shaft (12) rotates in the same direction as the main shaft (3). This rate of rotation is reduced by the gears from 2 to 10 per cent., depending on con-

ditions, and its weight with all the parts attached to it, is carried by the ball bearings (13) resting on the support (14). At the lower end of the quill shaft (12), is keyed the distributing

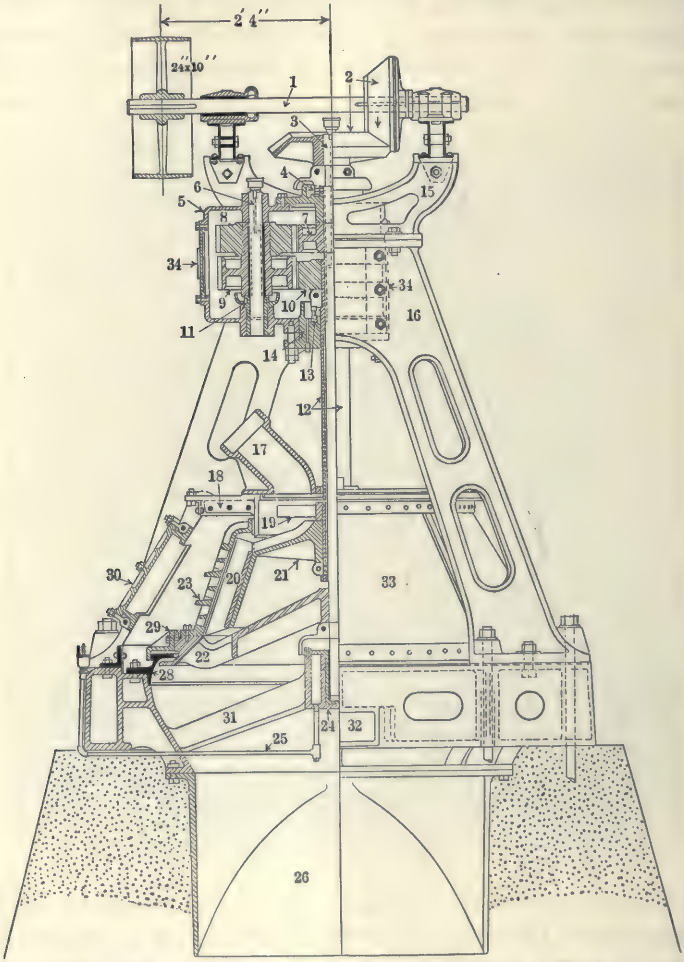


Fig. 154. Cross Section Showing Construction of Style "A" Elmore Dryer

cone (21) to which is bolted a series of high-pitched, helical scraping flights (20). Elements (10, 12, 20 and 21) therefore rotate as a unit and at a slightly reduced speed from the units (3, 22 and 23). The effect, therefore, is to have the screen on

the inside of the screen frame (23) slowly pass the scraping flights (20), although both may have an absolute rotation of several hundred r.p.m.

The process of extracting the moisture is simple. The wet material is fed through the inlet (17), falls on distributor (19), then on cone (21), when the centrifugal force throws it horizontally to the conical screen on the inside of frame (23). As the

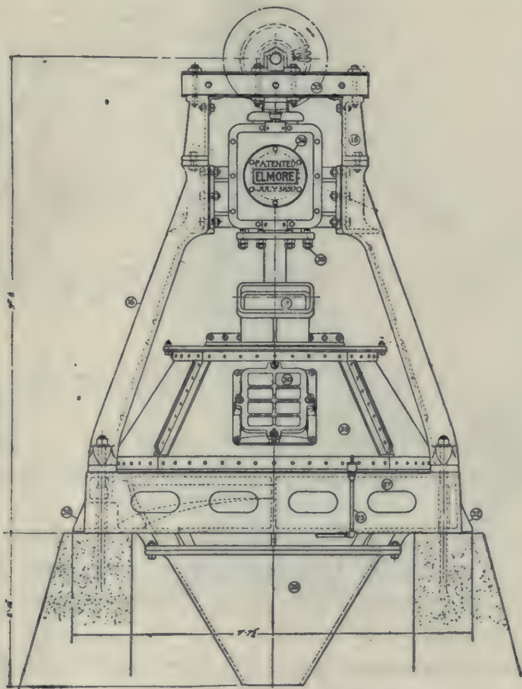


Fig. 155. Elmore Dryer Style "A"

screen slowly passes the flights (20), the water goes through the screen into the open space outside and, retained by the casing (33), falls into channels cast in the base (27) and flows out at opening (32). While the water is thus escaping through the screen, the solid matter is being gathered up in rolls at each of the flights (20), which are placed at such a pitch that the material slides down the face of these flights, is thrown off at their lower end and discharged against renewable ring (28).

From this point it falls through the center opening in the base casting and out of the machine through hopper (26) on to a conveyor or other means of removal. Rings (28 and 29) form a lock to prevent solids from passing to the water compartment or vice versa. Inasmuch as a comparatively small amount of

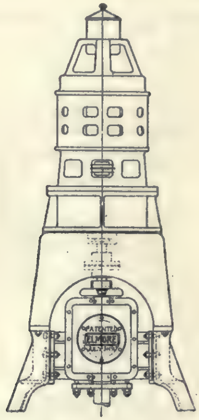


Fig. 156. Elmore Dryer with Direct Motor Drive

material is being conveyed by each flight at any one time, it will be seen that every opportunity is afforded for the water to free itself.

After having read and thoroughly understood the foregoing description of the Style A machine, the construction and operation of Style B will be readily seen. The main points of difference are as follows:

First—The differential gears (7, 8, 9 and 10) run in oil, in an oil tight gear case (5).

Second—The center shaft (3) supports the distributing cone (21) and scraping flights (20), while the quill shaft (12) supports the rotating spider (22).

Third—The rotating screen frame (23) is cast in one piece and is removed by taking off the hood (33).

Fourth—All bearings are of the ball type and self-aligning.

The operation is similar to that of the Style A machine. The material enters at the top (17) and receives the same treatment as it strikes the screen, the moisture passing out through open-

ing (32) in each side of the base casting, and the solid material falling down through the passages (26) cast in each side of the base.

Provision is made in both types of machine for adjusting the distance between the rotating screen and the scraping flights.

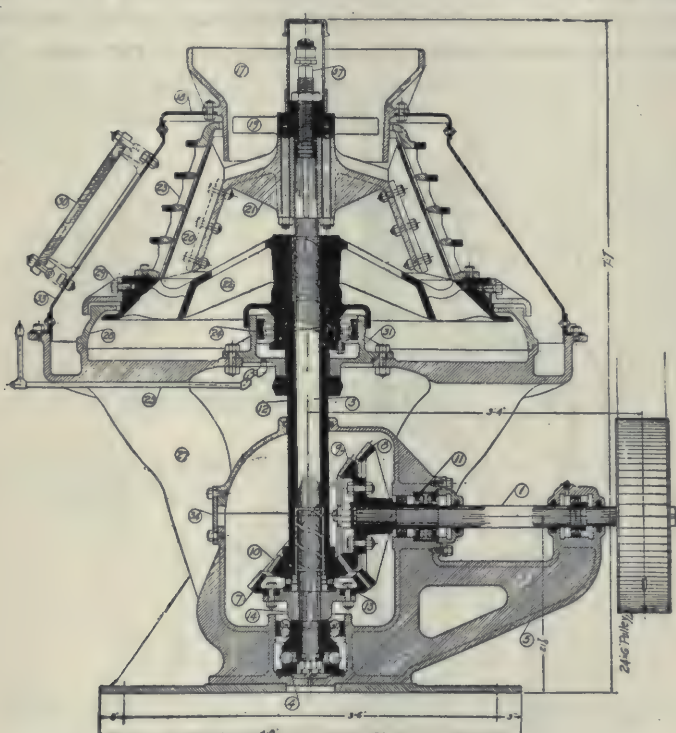


Fig. 157. Cross Section Through Elmore Dryer Style "B"

Capacity, Horsepower Requirements and Other Data for Elmore Continuous Dryers

Type	Inside diam. of Conical Screen Frame at bottom	Maximum Capacity in cu. ft. per Hour	Maximum H.P. required	R.P.M. Counter-shaft	Size of Driving Pulleys	R.P.M. Center Spindle Shaft	Net Weight
A	48″	3500	35	525–590	24 x 10	400– 450	19500
B	36″	1500	20	450–600	24 x 6	600– 800	10250
B	24″	800	15	600–900	20 x 6	800–1200	6000

Table 46

In the Style A, this is done by raising or lowering the support (14). In the Style B, the adjustment is made by the screw at the top of the center shaft (3), the hub of the rotating distributor (19) acting as the adjusting nut.

The results with the centrifugal dryer, as far as the delivery of dry coal is concerned, are very satisfactory. The moisture in the dried coal is reduced to an average of 6 per cent. The

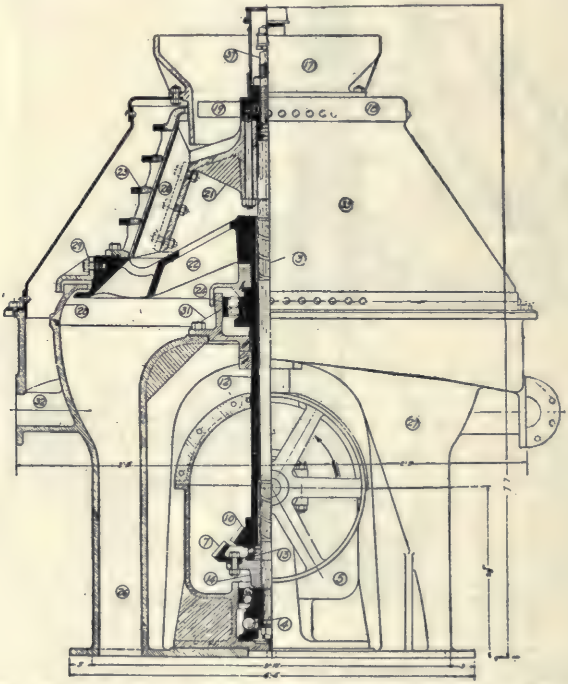


Fig. 158. Half Section and Front View of Elmore Dryer Style "B"

power requirements are not excessive, dryers with a capacity of 60 tons per hour using from 35 to 50 horsepower.

The greatest disadvantage noticed in the operation of centrifugal dryers can be traced to the rapid wearing of the screen plates which, on account of the small perforations, must be made of thin steel. A solution of this problem would be to use a protecting grate inside of the screens and to allow a thin layer of coal to remain on the screens. This would act as a

filter bed and protect the screen against the abrasive action of the coal.

By partly dewatering the coal going into the dryer and blanking the upper part of the screen plates a great improvement in the operation of the dryers was noticed, especially in regard to the fine coal retained, which before was forced through the perforations. A screen test of the coal dried in an Elmore drier gave the following results, showing that 16 per cent. of the coal leaving the dryer was finer than 10 mesh.

Size of dried washed Coal	Percentage
Held on ⅛ in. screen	70.22
Through ⅛ in.—held on 10 mesh	13.78
Through 10 mesh—held on 20 mesh	7.80
Through 20 mesh—held on 40 mesh	4.61
Through 40 mesh—held on 60 mesh	2.07
Through 60 mesh	1.52
	100.00

TABLE 47

The idea of employing a screw conveyor on the inside of a centrifuge and rotating this conveyor by means of differential

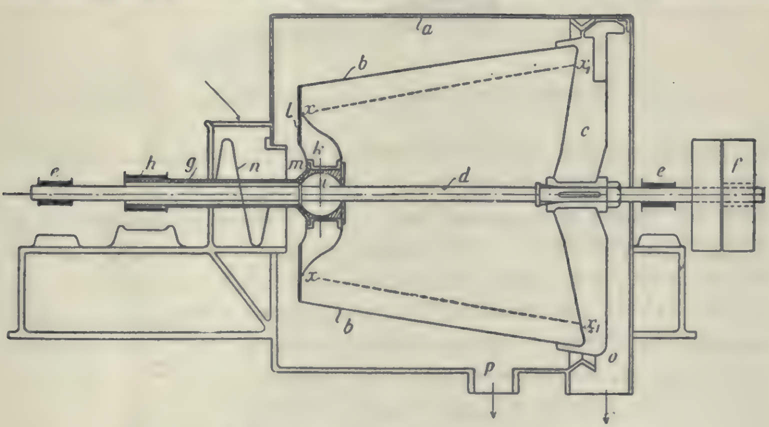


Fig. 159. Centrifugal Coal Dryer

gears at a slightly different speed from the centrifuge for the purpose of moving the coal continuously forward, was carried out by Hanrez (see page 61—Fig. 25) but without apparent

success. A centrifugal drier which avoids the use of a scraper inside of the revolving screen is shown in Figs. 159 and 160.

In a steel casing "a" a conical screen "b" is located. The arms "c" connect this screen with a horizontal shaft "d," which is supported in two bearings "e" and is driven by means of the pulley "f." On this shaft a sleeve "g" is placed. This sleeve is supported on its left end by a sliding bearing "h" which also permits of giving a slight eccentricity to the sleeve in regard to the main shaft "d." On its right end the sleeve fits over a ball "i" which is fastened to the main shaft "d." The sleeve carries by the arms "k" an annular plate "l" which

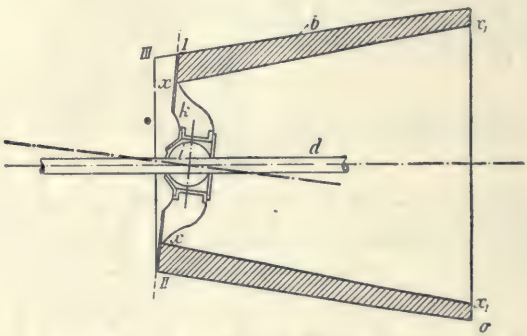


Fig. 160. Centrifugal Coal Dryer. Showing Method of Operation

closes the smaller end of the conical screen, with the exception of a central feed opening "m." The coal is fed to the centrifuge by means of a screw "n." The process of dewatering is carried on as follows: The washed coal is dewatered in an elevator to about 30 per cent. of moisture and conveyed by the screw "n" to the inside of the centrifuge, where it is pressed against the screen. By moving the bearing "h" so as to give the sleeve an eccentric motion, the annular plate "l" does not revolve in a plane at right angle to the main shaft, but in a plane: I–II. (Fig. 160.) This shoves the coal forward, because at each revolution an annular wedge space I–II–III is cleared of coal. An amount of coal equal to this space is discharged at each revolution at "o" and simultaneously replaced by fresh coal fed in through the screw "n." The water forced

out through the perforation of the screen is collected in the outer casing and carried away at "p."

This machine with a screen having an average diameter of 4 ft. 10 in. and a length of 20 in., making 300 r.p.m. dewatered 30 tons of coal to 7–8 per cent. moisture per hour. Washed coal containing 8 per cent. of material finer than 160 mesh was dewatered at a rate of 28 tons per hour. The dried coal contained at an average of 12 per cent. of moisture. The power required for a capacity of 28 tons per hour was 16 h.p.

At present, centrifugal dryers are the most efficient pieces of apparatus we have for the purpose of reducing the moisture in the washed coal below 10 per cent. It should also be stated that the coal feed to the dryers must be partially dewatered to at least 15 per cent. moisture, which can be easily accomplished by means of a dewatering elevator.

Filtering apparatus can only be used for fine coal and is best adapted for the dewatering of sludge. Such devices will be described in connection with sludge recovery.

CHAPTER XXIX

WATER CLARIFICATION AND SLUDGE RECOVERY

The clarification of the wash water and sludge recovery are carried on side by side in one process. The dirty wash water is separated into clear water on the one hand and concentrated sludge on the other. The clear water flows to the pump cistern and from there is put into circulation again by pumps. The concentrated sludge is either mixed with the washed coal, with or without further treatment, or stored away in separate bins for boiler-house use; or even in the worst case wasted on the refuse dump. The materials to be considered consist of the overflow water from the settling tanks and the dewatering apparatus.

The process of clarfying is carried on either in large settling basins or in a series of pointed boxes (*spitzkasten*). The employment of clearing basins has been almost abandoned for reasons previously given. The use of spitzkasten has never become popular on account of the large floor space required and the difficulty of removing the concentrated sludge. In a few isolated installations conical clearing tanks of large dimensions, similar to the Callow tanks, have been built but the resulting sludge could not be drawn off in a sufficiently concentrated state or with any degree of regularity. The Dorr thickeners which were taken over from ore-dressing plants have given thus far the most satisfactory results.

The clarification of the wash water must be carried out to such a degree, that considering the necessary addition of fresh water no increase in specific gravity shall occur. Since the quantity of fresh water required to make up for the loss caused by evaporation, the water carried away by the coal, refuse and sludge and by leakages, can be easily determined, we can state: The water clarification is to be carried to such a point that the addition of fresh water shall not exceed the loss of wash water.

This means that no water shall be wasted on account of its being too dirty to be put back into circulation. The reason for this is that the cost of water, on account of the immense quantities used, is quite a consideration. A washery treating 2000 tons in eight hours circulates in that time over 1½ million gallons of water.

The cost of water clarification and sludge recovery should be as small as possible. Little has been done in the way of improvement in this direction. The apparatus employed for settling out the sludge should be arranged in such a way that unnecessary power requirements for the conveying of sludge and water may be avoided. Two methods can be used to accomplish this: (1) The settling apparatus may be located at such an elevation that the overflow water from the tanks can flow by gravity to the clarifying apparatus. This will, however, require in most cases a lifting of the cleared water and the concentrated sludge to their respective places. (2) The clarifying apparatus may be placed sufficiently high so that the cleared water as well as the concentrated sludge can flow by gravity to the places where they are to be used. In this case the overflow water from the settling tank must be lifted to the top of the clarifying apparatus. This latter arrangement has the advantage that it avoids the troublesome elevating of the concentrated sludge and furthermore that it makes the space underneath the clarifying apparatus accessible. The materials used for the construction of the settling tanks are usually either timber (redwood), steel or reinforced concrete. The concentrated sludge can be conveyed by means of centrifugal pumps, diaphragm pumps or by compressed air. Centrifugal pumps can be used when the sludge must be elevated above the permissible height of suction. Diaphragm pumps can only be used on suction lifts and are really used more often as a device wherewith to regulate the flow of sludge than as a conveying medium. Compressed air has been largely used in Europe for conveying the sludge from the clearing basins. In Fig. 161 the arrangement of such an installation is clearly shown.

The four discharge points of the clearing basin *A* are connected by the pipes *P* with the tank *T*. Communication between any of the four discharge points of the clearing basin

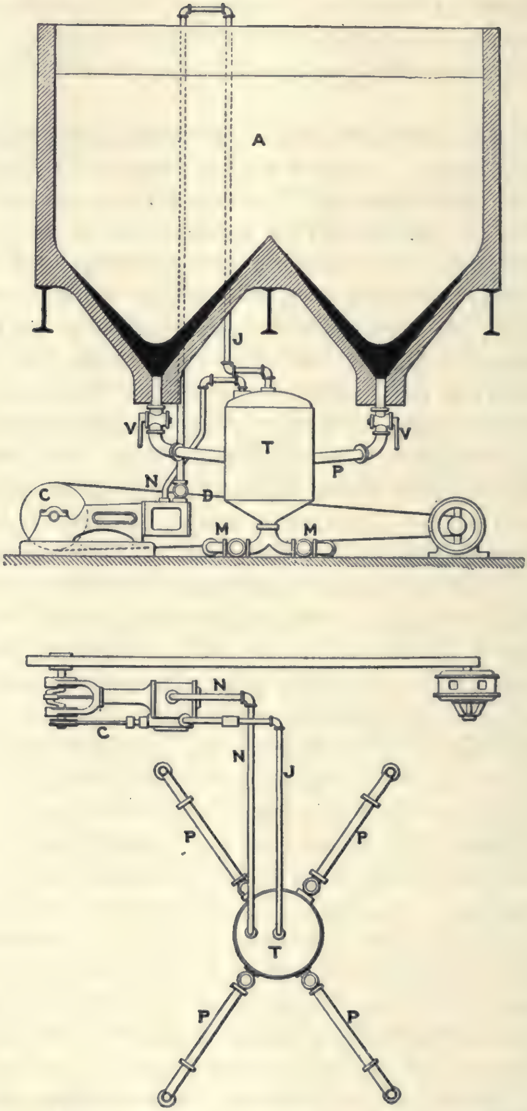


Fig. 161. Apparatus for Conveying Sludge by Compressed Air

and the tank *T* can be made and interrupted by the valves *V* located in the pipes *P*. From the tank *T* the pipe *J* leads to the air compressor *C*. The three-way cock *D* permits connection of the tank *T* through the pipe *J* either with the atmosphere or with the compressor *C*. To start operation, the pipe *J* is connected with the atmosphere and the valve *V* is opened at the same time. This permits the sludge to flow into the tank *T*. Should the sludge not flow as freely as desired, the cock *D* can be turned in such a way that the compressor takes the air from the tank *T*, creating thereby a partial vacuum in the tank. This accelerates the flow of the sludge. A float indicates the amount of sludge in the tank. As a further safeguard the pipe *J* is carried well above the top of the clearing basin, so that no sludge can enter the compressor. When the tank has been filled with sludge, the valve *V* is closed, the compressor started, delivering compressed air into the tank through the pipe *N*. Now, by opening the valve *M* the sludge is forced out of the tank.

The question yet remains as to whether pumps or compressed air is preferable for the conveying of sludge. Conveying by means of compressed air is mechanically more perfect. The sludge can be thicker than if handled with pumps, without increasing the wear and tear on the apparatus. But the cost of the installation is considerably higher and the operation requires more careful attention. Smaller washeries will therefore prefer pumps, especially if the nature of the sludge is such that the wear and tear on the pumps is not excessive. Larger washeries having great quantities of sludge to handle should consider compressed air as a medium for conveying it, especially as an air-compressing plant is more or less a necessity around a mine.

The following table shows some results obtained with *spitzkasten* clearing basins:

Capacity of Washer per Hour in Tons	Total Clearing Surface of Spitzkasten in Sq. Ft.	Number of Boxes	Cleared Water per Minute in Gallons	Concentrated Sludge per Minute in Gallons	Power Required to Lift Sludge, Hp.	Power Required to Lift Water, Hp.
100	860–1620	3– 6	1765–4414	4.4–22	5–15	60– 80
150	1076–2152	5– 8	2647–6621	9.0–33	6–30	70–100
200	2152–3230	5–12	3530–8828	17.5–44	10–30	90–130

TABLE 48

As mentioned previously, the process of clarifying the water is carried on either in large settling basins or in a series of *spitzkasten*. In actual fact, however, little has been accomplished in this respect. In most cases the same water is used over and over again until it becomes too thick for any further use. It was, and still is, the common practice to run a washery with one filling of water, according to the nature of the raw coal, say for from three days to two weeks, and at the end of this period to empty all the jig and settling tanks and fill them up again with fresh water. This is a crude method, but for the lack of something better it was tolerated even if every washerman condemned it.

Fig. 162 shows the construction of a settling tank with attached "*spitzkasten*." The accumulated sludge is removed from the apexes of the *spitzkasten* by means of a centrifugal pump, which deposits this sludge either on the washed coal or carries it to continuous drum type filters.

The deplorable condition mentioned above, namely the practice of changing the wash water rather than clarifying it, remained unchanged until the advent of the Dorr thickener. This apparatus embodies a highly efficient, economical and mechanically perfect device for settling out the fine impurities. The Dorr thickeners make it possible to recover as a clean, granular coal material which normally goes to waste, and at the same time furnishes a wash water as pure as originally supplied to the system. The operation of these thickeners is entirely automatic and continuous. Power and operating cost are almost negligible. They may be installed in any form of circular tank or basin up to 200 ft. in diameter. If the nature of the ground permits, simple excavations with concrete overflow rims are often used.

The settled solids are continuously discharged in the underflow as thick sludge. The operation of the thickener may be so controlled as to deliver an overflow either entirely clear or containing a certain percentage of solids. For an installation of given size, the natural settling rate of the material being handled and the rates of feed and of underflow determine the amount of solids in the overflow.

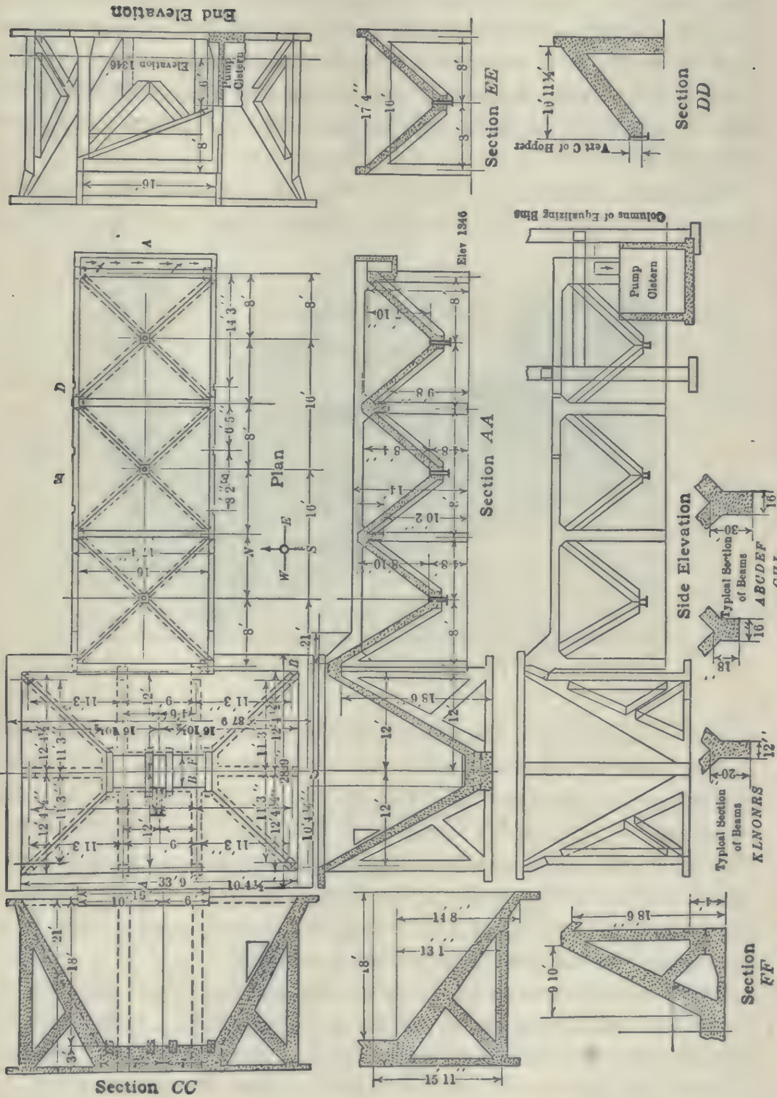


Fig. 162. Settling Tank for Washed Coal. Reinforced Concrete Construction

It has been found that the thickener works best if the feed does not contain material larger than 20 mesh. As the overflow from the washed-coal settling tanks, and more especially from the centrifugal dryers, contains a good deal of coal bigger than 20 mesh, it is advisable to put in a classifier ahead of the thickener for the purpose of removing the coarse particles of coal in a dewatered state and to pass only the fine slime to the thickeners.

The Dorr classifier, as shown in Fig. 163, consists of a shallow, rectangular tank with a sloping bottom. The tank may be set

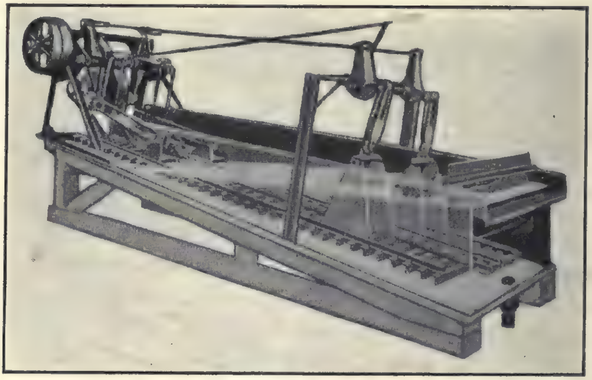


Fig. 163. Dorr Classifier

at any desired slope, usually about 2½ in. to the foot. The feed to the classifier is continuous; all granular material settling to the bottom of the tank is raked up the incline by reciprocating rakes and discharged at the high end above the water level. The fine and more slowly settling solids overflow with the excess water at the opposite end. Broadly speaking, the slope of the bottom, the speed of the rakes, and the dilution of the feed determine the character of the two products.

The classifier serves to dewater the granular coal and to remove the remaining small amounts of coal slime, which can be settled out in the thickeners. Fig. 165 shows a Dorr thickener of 70 ft. diameter with concrete tank. The flow sheet given in Fig. 164 shows a typical arrangement for a water-clarification and sludge-recovery plant.

The power required for operating a 70-ft. Dorr thickener is about 1.5 hp., and the speed of the rakes is approximately from 4 to 8 revolutions per hour.

Under normal conditions of the overflow water from the washed-coal settling tank 30 gal. per minute can be cleared per 100 sq. ft. of settling area, so that a 70-ft. thickener will be able to handle the overflow water from a washery treating 100 tons of coal per hour, if we assume that the water required for wash-

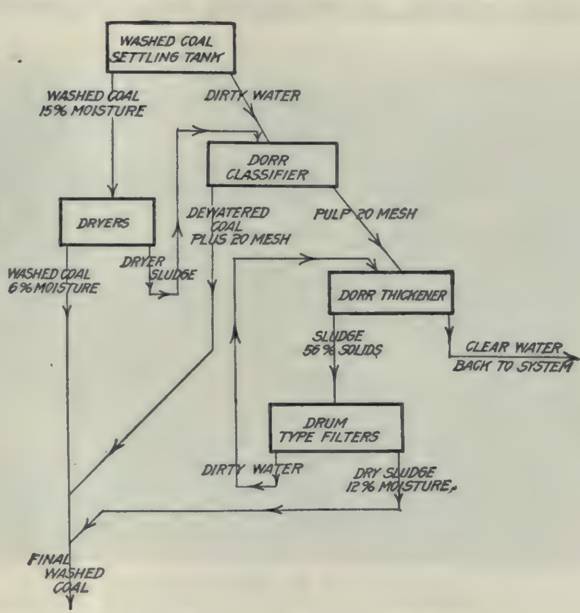


Fig. 164. Flow Sheet for Water Clarification and Sludge Recovery Plant

ing will be three times the weight of the coal, or 723 gal. of water per ton. The overflow can be easily cleaned so that it does not contain more than 2 grams of solids per liter (approximately 117 grains per gallon) or only 0.2 per cent. of solids. The underflow or the sludge can be concentrated so that it will contain up to 58 per cent. of solids. This is about the limit of density that will still permit the handling of the sludge through pipes or with pumps.

The Dorr thickener mechanism is shown in Fig. 166 installed in a steel tank. The tank may be constructed either of steel,

wood or concrete as the nature of the service and comparative cost may dictate. The feed enters the tank at the center from above. The solids settle to the bottom of the tank, while the liquid overflows at the periphery into a collecting trough. The thickener mechanism, suspended in the tank from the superstructure above, consists of a central vertical shaft with radial arms equipped with ploughs to bring the settled solids, by means of a slow rotation of the mechanism, to a discharge opening at the center of the bottom. The settled solids as a thick sludge

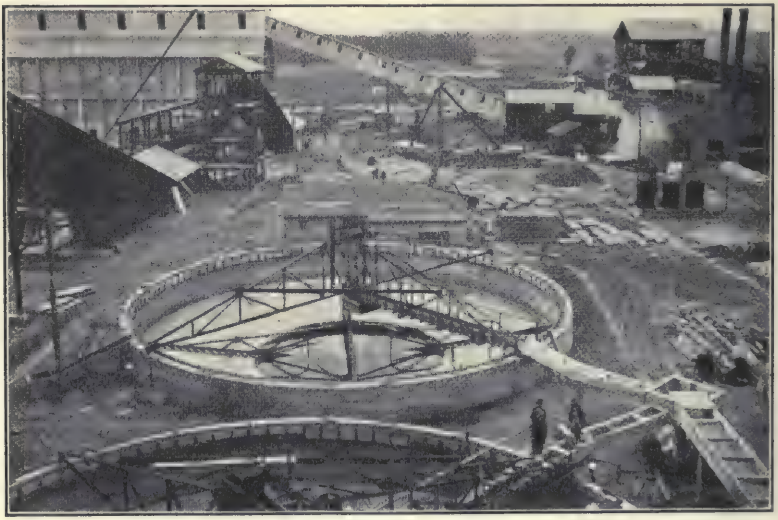


Fig. 165. 70 Ft. Dorr Thickener

can be discharged at this point by gravity or piped to a pump for delivery to any desired point.

The superstructure carrying the mechanism may be of steel or wood, and may be supported by the tank or independently. If convenient the superstructure may be incorporated with the roof trusses of the tank covering, should such be provided. Power is delivered to the mechanism by means of pulley and worm reduction gearing.

Arrangements are provided for quickly and easily raising the shaft and arms so that they will not become embedded in the settled solids should the power be shut off for any length

of time. The shaft can be gradually lowered again while running.

The operation of the thickener may be so controlled as to deliver an overflow either entirely clear or containing a desired percentage of solids. The proportion of liquid in the sludge discharge can also be varied at will between wide limits. For a thickener of given size the natural settling rate of the solid matter in the material being handled and the rates of feed and underflow determine the amount of solids in the overflow.

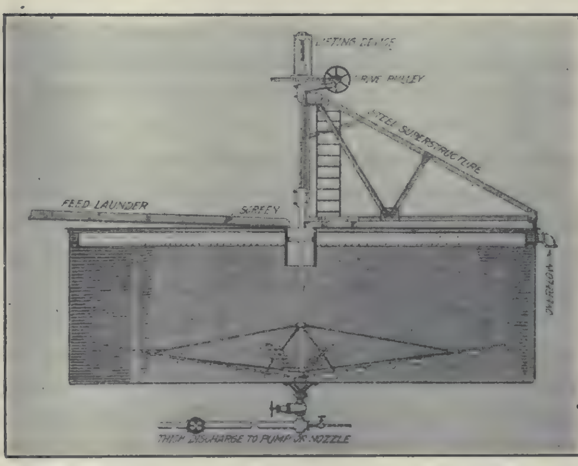


Fig. 166. Dorr Thickener Mechanism Installed in Steel Tank

The thickener may also be operated to separate the suspended solids into two sizes. Coarse particles settle more rapidly than fine ones of the same specific gravity, so that it is possible, by suitable adjustment of operating conditions, to secure a reasonably clear-cut separation of the solids at a given fineness. When so used a thickener is termed a hydroseparator.

The following results of actual operation show the efficiency of Dorr thickeners for bituminous as well as anthracite coal.

Bituminous Coal. A plant washing 4000 tons of raw coal in 16 hr. for coking, has an installation of four Dorr thickeners. Three of these, 70 ft. in diameter, take the overflow from the washed coal settling basin, and the fourth, 50 ft. in diameter, the overflow from the refuse basin.

The coal slush, amounting to 6157 gal. per minute, contains 1.25 per cent. solids, or 275 tons per day of coal. Of this total 97.87 per cent., or 269 tons, is recovered in the form of a sludge carrying 48 per cent. moisture. This sludge is delivered on top of the coarser coal on the washed coal belt.

The overflow from the larger thickeners, carrying less than 0.15 per cent. solids, together with the overflow from the 50 ft. refuse thickener, is returned to the washery circulation. This return constitutes 98 to 99 per cent. of the water in the feed to the thickener.

Exclusive of plant leakages, the net consumption of water is thus reduced to approximately 40 gal. per ton of raw coal washed or the amount carried away in the washed product, and the refuse.

Anthracite Coal. A typical Dorr recovery plant is handling the slush from an anthracite breaker producing 5000 tons per day of 8 hr. The slush is made through a 3/64 in. round hole screen, the quantity varying from 3000 to 4500 gal. per min., the average ratio of water to solids being about 30 to 1. The solids average 45 long tons per hour.

The plant consists of:—One Dorr hydroseparator 26 ft. in diameter by 7 ft. deep, the arms of which revolve at 1 r.p.m., three Model "C" duplex Dorr classifiers, 5 ft. 6 in. wide by 18 ft. long, speed 16 strokes per minute, slope 2¼ in. per foot; and a scraper line for removal of the finished product.

The slush is delivered at the center feed well of the hydroseparator. The overflow from the separator, consisting of the greater part of the water and extremely fine material, is run to waste. The underflow carrying all the coarser granular material gravitates to the Dorr classifiers where the final separation and dewatering takes place.

Apart from the scraper line for the removal of the finished product, the entire recovery plant requires 5 to 6 h.p. Attendance requires only a small fraction of one man's time.

In cases where the slush contains a large percentage of ash, this ash can be effectively reduced at a small cost by the use of concentrator tables. Where this is done, such tables are installed between the hydroseparator and the classifiers.

The attached skeleton flow sheet gives typical results on anthracite slush, both with and without concentrator tables.

In either case the final coal product (classifier discharge) is discharged at approximately 30 per cent. moisture. Either in cars or stock pile, it drains rapidly to 12 to 15 per cent. moisture.

It should be pointed out that the procedure in any given case depends upon the use to which the recovered fuel is to be put. If it is to be mixed with other steam sizes and used for fuel at the mine boiler plant adjustments are made to give a separation at 60 to 100 mesh, as it has been found that coal finer than this introduces difficulty in keeping the boilers up to the desired rating. Within reasonable limits the ash content is of secondary importance.

If the recovered fuel is to be used for briquetting, ash should not exceed 16 to 18 per cent. (which in most cases involves tabling) but there are no limitations as regards fineness. If the recovered fuel is to be pulverized and used in this form for firing, there are, of course, no limitations as to fineness, and a low ash content is not essential. The chief objection to high ash in coal used for this purpose is the consequent reduction of the fuel value of this coal and the increased cost of pulverizing. In all but the first case, the fuel must be further dried.

The flow sheet given below, shows the results in the recovery of mine fuel. The recovery normally amounts to 25 to 40 per cent. of the mine fuel consumption. In tonnage, the mine fuel consumption amounts, in the anthracite field, to approximately 10.5 per cent. of the production.

In the recovery of slush coal by the method outlined, the requirements in each of the three cases cited may be met by suitably adjusting the size of equipment installed, to the result desired. Operating adjustments also permit of varying considerably the character of the product.

Broadly speaking, slush recovery plants may be so designed and operated as to produce any of the following results:

I *a*—All the slush solids in the form of a sludge carrying 40 to 45 per cent. moisture.

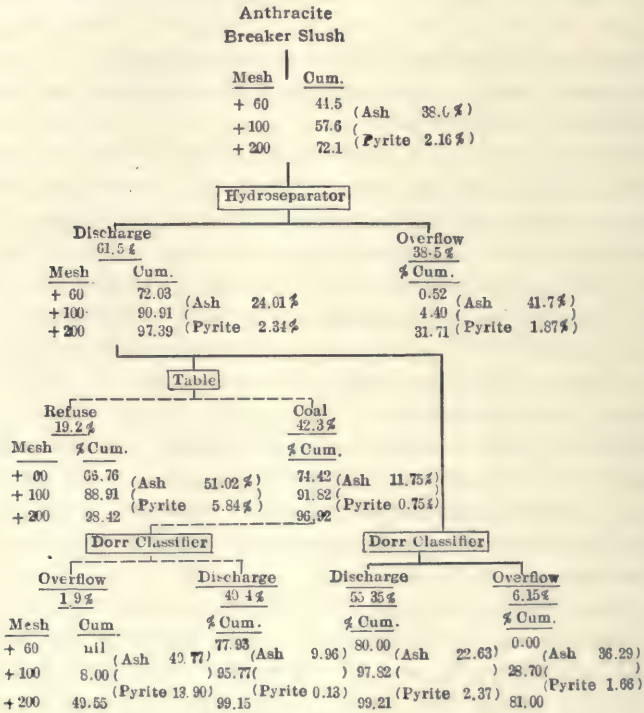
b—Substantially clear water amounting to 80 to 85 per cent. of the water in the slush.

II *a*—All the granular solids (separation at 60 mesh or finer as desired) practically free from slime and silt. This product will stack.

b—A waste product carrying the balance of the slush solids and the bulk of the water.

III Either I or II with the ash in the recovered coal reduced by tabling, to a percentage approaching that of "stove" and "chestnut" coal.

In all cases 80 to 85 per cent. of the slush water may be recovered in a substantially clear condition, available for re-use in the breaker.



Note. Screen analyses refer to dry solids
Figures underlined give percentages
by weight of solids in orginal-slush
feed.

Flow Sheet of Dorr Installation Treating Anthracite Breaker Slush

J. R. Campbell in his paper on "The Mechanical Separation of Sulfur Minerals from Coal" gives the following results from two 70 ft. Dorr thickeners:

The use of the Dorr thickeners has been very successful though we experienced some trouble at first due to inexperience. The following is a typical operation of these thickeners under normal conditions:

	Influent	Effluent	Underflow
Water, per cent.	98	99.7	47.2
Solids, coal, per cent.	2.0	0.3	52.8
Specific gravity	1.0052	1.0008	1.1580
Total, per cent.	100	97	3
Tons per hour	500	485	15

TABLE 49

The above is based on the operation of two 70-ft. Dorr tanks handling the wash water from approximately 1200 tons of coal washed in 8 hr. The overflow water contains but a small percentage of solids and is in fine condition for reuse. The underflow, or sludge, is in good condition for handling in a number of ways and, from an analytic standpoint, takes on the character of the washed coal proper.

The following are possible solutions of the sludge problem: It may be pumped by means of the diaphragm pump direct to the washed-coal elevator on top of the coal in the dewatering buckets and passed through the mechanical dryers with the coarse coal, or it may be pumped direct to the dryer, but this practice builds up the circulating system and is almost certain to cause trouble sooner or later.

The second way is to operate in an open circuit and pump the 50-50 sludge direct on top of the washed and dried coarse coal, which eliminates it from the system altogether, although this practice adds about 3 per cent. moisture to the final washed product.

(3) The third, and perhaps the most logical method, is to take the sludge from the Dorr tanks and put it through a continuous filter of approved type and dehydrate it to 12 per cent. water and under, after which the cake can be added to the dried coarse coal. This method would give a final washed product of minimum water content and would add less than 1c. per ton to the cost of the washed product.

(4) A fourth way would be to take the cake from the continuous filter and completely dehydrate it in a direct heat drier, adding the powder to the washed and dried coal. This method would be more expensive and seems of doubtful value.

In connection with the sludge recovery J. R. Campbell developed a formula for determining the percentage of solids in the influent, effluent, and underflow from the specific gravity of the various solutions, which seemed the most expeditious way of reaching conclusions rapidly without the tedious and laboratory way of filtering and weighing the solids, though this process should be followed at frequent intervals as a check.

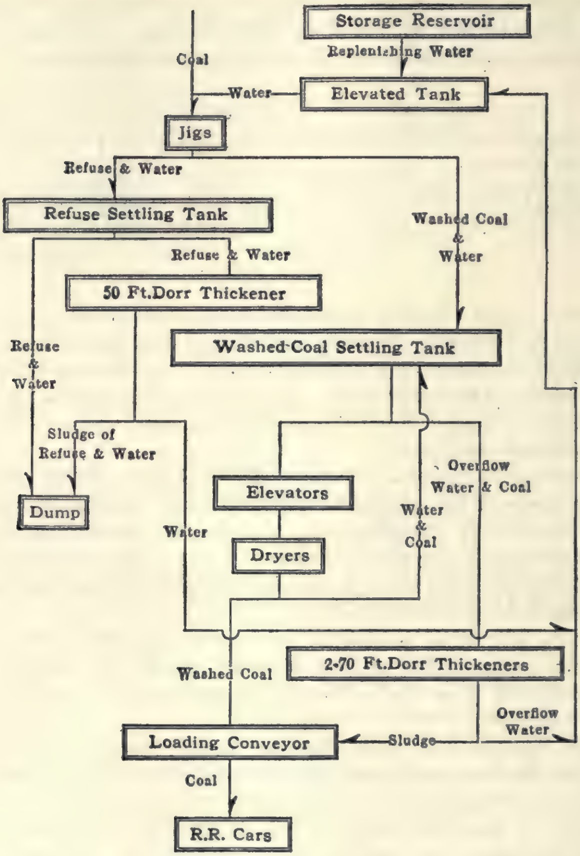


Fig. 167. Flow Sheet for a Water Clarification and Sludge Recovery System

Let A = specific gravity of water, B = specific gravity of coal (say 1.35), and X = specific gravity of solution in question; then,

$$\frac{B(X-A)}{X(B-A)} \times 100 = \text{per cent. solids in solution.}$$

To illustrate, we will use the test on Dorr thickeners, the underflow having a specific gravity of 1.158.

$$\frac{(1.158 - 1.000) \times 1.350}{(1.350 - 1.000) \times 1.158} \times 100 = 52.6 \text{ per cent. solids.}$$

The weighed percentage of solids in the underflow was 52.8 per cent. In a similar way the amount of influent, effluent, and underflow of the Dorr tanks can be determined, given any one of the three quantities from the specific gravities of the solutions and consequently the water consumption of the plant, if no meter provisions are made. As it is comparatively easy to measure the underflow, the calculation is usually made with this known quantity as to the amount in a given length of time.

CHAPTER XXX

SUBSEQUENT TREATMENT OF SLUDGE

A sludge containing too much impurity to be mixed in with the washed coal entails great losses upon the economic operation of a washery. Furthermore, this sludge, if wasted upon the refuse dump, will fire in course of time and is liable to cause thereby much trouble and damage.

The loss of combustible with the sludge is of greater importance with coking coal, where the fines are of greater value than with fuel coal. Therefore, efforts to treat the sludge for fine-coal recovery are advisable. Many different methods have been tried, but thus far the results obtained have been only mediocre. This is not surprising, considering the fineness of the material. The possibility, however, of a separation can be based upon the fact that even the smallest particles of coal show a granular structure, whereas the fireclay or the crushed slate are of such a fineness that the particles are held in suspension in the water.

Successful separation of coal from the sludge demands a distinct difference in the size of the grains. The requirements are that the fireclay shall be removed from the sludge as much as possible without great loss of coal. Up to the present time the only successful method for such a separation depends upon a swift current of fresh water in the shape of sprays, but the tendency at present leans toward the use of apparatus now employed in ore-dressing plants, such as slime tables or Dor classifiers.

One important piece of apparatus at present operating at least halfway successfully is the Kohl-Simon screen, shown in Fig. 168. The screens having fine brass-wire mesh (65 mesh to the inch) are hung at their upper ends on the swinging rods *A* and on their lower ends on the bails *B*. The eccentrics *C* give the screens a reciprocating motion and at the same time the double cams *D* impart to the screens a forcible vibrating motion.

The sludge to be treated is sluiced onto the screens through the launder E. Fresh-water sprays are forced against the sludge through the pipe F, which has ⅛-in. holes over its whole length on the under side. These sprays wash the fireclay, which has finer grains than the coal, through the screens into the launder G. The fine coal freed from the fireclay travels over the screens

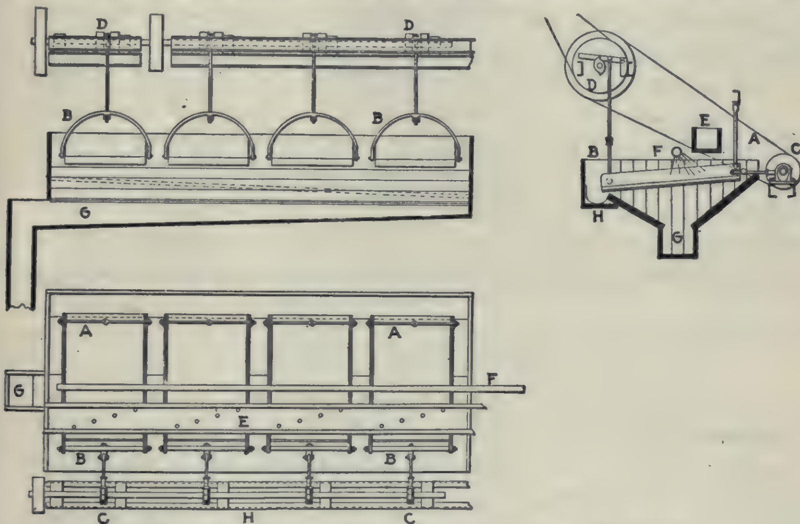


Fig. 168. Kohl-Simon Screen for Treatment of Sludge

and is collected together with part of the wash water in the launder H. The following results were obtained with this apparatus:

Daily Input in Gallons	Solids Per Cent.	Fresh Water Used in Gallons	Clean Coal Produced			Resulting Dirty Water		
			Tons	Ash Per Cent.	Moisture Per Cent.	Amount of Water in Gallons	Solid Matter Ash Per Cent.	Solid Matter Coal Per Cent.
60,000	10.39	63,000	4.78	8.16	14.78	120,000	39.74	60.76

Table 50

Instead of shaking screens, revolving screens are also used. These screens have a perforated zinc mantel with a fine brass-wire mesh fastened securely thereto on the inside. The fireclay is washed through the screen by fresh-water sprays, just as with the shaking screens.

The use of slime tables is still in an experimental state, but judging from the results obtained in the ore-dressing plants a successful operation can be expected. The Dor classifier has been used in the anthracite region to recover coal from the breaker slush. Over 55 per cent. of the coal contained in the slush was recovered and the ash reduced from 30 per cent. to 22 per cent. This was further reduced to 16 per cent. by treating the recovered coal on tables.

All known methods of treating the sludge can only be used to a limited extent. Success can only be expected if the impurities are in finer grains than the coal. This requires preliminary investigations, which will also give data in regard to the size of the screen perforation. Sludge with 30 to 40 per cent. ash treated over screens with sprays gave a recovery of about 20 to 30 per cent. of coal with from 8 to 10 per cent. of ash.

Drying of the Sludge

The sludge, treated or untreated, must in every case be dewatered before it can be mixed with the washed coal. On account of the fineness of the material centrifugal dryers cannot be taken into consideration. Heat dryers are not an economical proposition and therefore we must have recourse to filters. The requirements for filters are identical with the requirements for all the other apparatus used in a washery—that is, continuous operation, high efficiency, simplicity of construction, low cost of installation and operation, and durability.

Nobody will expect that any one piece of apparatus will fulfill all of the foregoing requirements, but in regard to filters the continuous drum-type comes nearer to doing it than any other. Sludge containing 35 per cent. solids and 65 per cent. liquid has been dewatered with it to only 20 per cent. moisture. This will make it appear feasible that a sludge with 56 per cent. solids and only 44 per cent. liquids can be brought down to at least 10 to 12 per cent. moisture. This would put the sludge in such shape that it could be mixed with the washed dried coal without increasing the moisture content of the final product to any appreciable extent.

J. R. Campbell is of the opinion

"that the most logical method of solving the sludge problem would be to take the sludge from the Dorr thickeners and put it through a continuous filter of approved design and dehydrate it to 12 per cent. moisture and under; after which the dried sludge cake can be added to the dried coarse coal. This method would give a final washed product of minimum water contents and add less than one cent per ton to the cost of the washed product."

G. W. Evans, coal mining engineer of the Northwest Experiment Station, U. S. Bureau of Mines, Seattle, stated at the British Columbia International Mining Convention that

"A coal-cleaning plant operating along most modern lines does not waste very much except the color in the water. Probably some enterprising engineer will attempt to recover the color by means of an Oliver filter."

The purpose of a filter is however not only to remove the color in the water, but also to put the sludge in such shape that it can be added to the dried coarse coal.

Filtration. For convenience in discussion we can classify most of the filtering problems into three groups.

First: Those in which the suspensions are extremely fine or of a flocculent or collodial nature, causing a slow separation of the solid suspensions from the liquid.

Second: Those in which the suspensions separate themselves readily from the liquid content, and form a filter cake of substantial thickness in a short period of time.

Third: Those in which the suspensions are of such a coarse granular nature that the liquid content can be readily withdrawn but the solids are so coarse and of such a high specific gravity that they fail to cohere with one another to form a compact filter bed.

In the first group the open tank filter is generally the best type of apparatus to employ.

In the second group the rotary filter will give the most satisfactory results.

In the third group the rotary hopper dewaterer is best adapted to the problem.

The rotary filter made its appearance in the latter half of the 19th century in Belgium, where the idea of a rotating drum with a perforated surface covered over with filter medium was conceived. It remained for George Moore, metallurgist, how-

ever, to invent the multiple compartment rotary filter, United States Patent No. 746552. The invention of the multiple compartment rotary filter by Moore followed closely on the heels of the Moore process, well known in metallurgical lines.

The multiple compartment rotary filter is a natural outgrowth of modern business efficiency methods. The tendency of the present day is to eliminate intermittent processes and to replace them with continuous and, if possible, automatic operation. A continuous method means maximum output at the most econom-

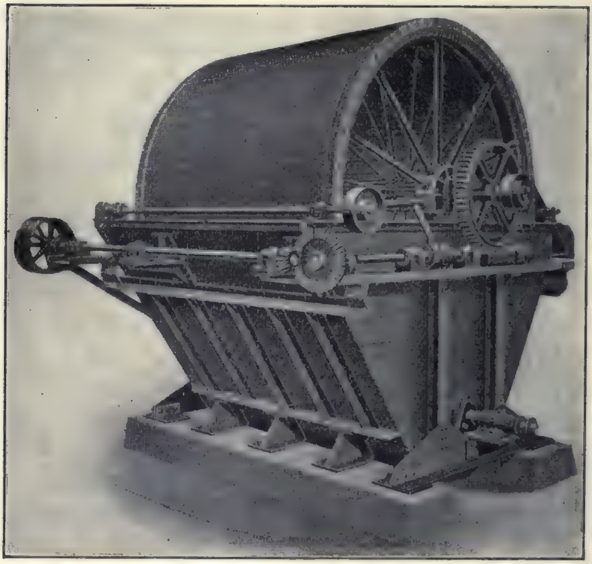


Fig. 169. Portland Filter

ical rate, and automatic machinery means the standardization of product and relief from the uncertain labor market.

At present there are four types of continuous filters on the market, namely, the Portland, the Zenith, the Oliver, and the American. None of these machines have been installed in a commercial washery but sufficient laboratory tests have been made to show their capacity and efficiency.

The Portland filter shown in Fig. 169 is of the rotary drum type. It consists of a series of panels carrying a porous filter medium, arranged in the form of a drum which is adapted to

rotate in a tank containing the material to be filtered. Each of the panels or sections which make up the drum is entirely independent of the others, and its action is controlled by an automatic valve which serves the entire machine.

This valve is one of the distinctive features of the machine and permits a wide variation in the working of the filter according to the class of material being handled and the precise requirements of the method of operation.

The panels are made up of heavy redwood planking, and cast iron, or other suitable material, which forms an impervious back to the sections. Drainage channels are provided on the face of the panel, and upon these the filter medium consisting of a layer of rolled wire cloth, a layer of burlap, and a final surface of a cotton fabric of proper texture, are successively placed. In exceptional cases the filtering medium consists of a special woven wire cloth of non-corrosive metal, which serves the same purpose as the cotton fabric. While the expense of manufacture is great, the initial cost of a filter covering of this kind is under certain conditions more than counterbalanced by its correspondingly long life.

The entire drum is wound helically with wire, leaving the filter surface exposed between the convolutions, which are about one-half inch apart. The wire cloth is a permanent part of the panel, only the burlap and drill, together with the winding of wire requiring renewal, and these only at long intervals.

The lower part of the drum is submerged in a tank containing the material to be filtered and is slowly rotated—one revolution in five to eight minutes—taking on a layer or cake of solids which is discharged before the same portion of the filter surface again enters the pulp. To build up the cake and remove the clear liquid a vacuum is maintained, and to assist in discharging the cake and cleanse the filter medium a pressure of air is admitted to the interior of each panel at the proper point in the cycle of revolution.

A scraper maintained in contact with the working face of the drum, just above the top of the tank on the descending side, receives the cake as it is dislodged by the air and deflects it outside the tank for disposal.

The Zenith rotary filter is shown in Fig. 170. It consists of

a hollow drum mounted upon a horizontal axis, the lower portion of the rotating drum dipping into the container holding the slurry to be filtered. The outer surface of the filter drum is divided into a number of uniform shallow compartments, each compartment being connected by separate pipe lines to the central valve hub which is cored out to receive the pipes from each compartment. The compartments are covered with wire screen suitably supported and over this, encircling the entire drum is stretched the filtering medium, each compartment being kept

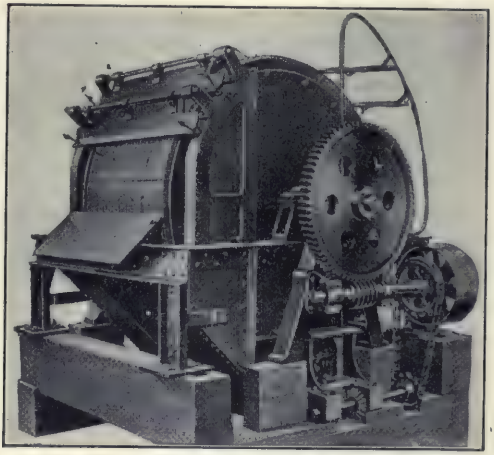


Fig. 170. Zenith Filter

separate and distinct and giving a smooth peripheral surface to the drum.

The central valve hub rotates against a stationary valve cap which is so arranged that each compartment can independently be subjected to suction, or neutral, or pressure during any portion of the cycle. Provision is made in the valve cap for applying suction and for drawing off the filtrate and wash water separately if desired.

The container in which the drum rotates is hopper bottomed and provided with a mechanical agitator for keeping the slurry in a constant state of agitation during filtration. A scraper is fitted to the edge of the container, parallel to the axis and set at an extremely short distance from the face of the drum. It is

the purpose of the scraper to remove the cake from the surface of the drum just before that portion of the drum is about to dip into the solution. Washing of the cake is accomplished by sprays which are so placed as to play upon the surface of the drum just after the drum with its accumulated solids emerges from the container.

The solids, held upon the filtering surface by suction, pass out of the slurry, are washed by the sprays and discharged over the scraper as a dry cake in the form of a ribbon from whence they may be conveyed as desired.

The surface of the filtering medium is protected from abrasion by wire which is wound around the drum in the form of a helix. All parts of the machine are sturdily constructed; the castings are perfect, the wearing surfaces nicely machined and ground. The drum is driven by a large well cut gear and worm. All the parts of this machine are made for rough service and long use and for this reason the items of repair and renewal are low.

Every part of the filter is easily accessible. The pipes are extra large and the valve sector shaped so as to readily take care of the large amounts of free air and filtrate which are drawn through the filtering medium thus giving a maximum efficiency per square foot of active filtering surface and permitting of no reduction in vacuum between valve and filtering medium. This fact is of special importance and is a distinctive feature of the Zenith rotary filter.

The drum usually is rotated at a rate of about one revolution in five minutes. The container is kept filled with the slurry to be filtered, the excess being taken care of by an overflow pipe, and the solution is kept in agitation by means of the mechanical agitator. Vacuum is maintained by a dry vacuum pump or other means of creating suction of ample capacity to take care of the filtrate plus the free air which is drawn through the filtering medium. When operated with a dry vacuum pump, a tank acting as a receiver for the filtrate, is interposed between the pump and the filter. This tank is first exhausted by the pump and suction to the filter is applied from here. The suction causes the clear filtrate to be drawn through the filtering medium, large pipes and valve to the receiver.

From here the filtrate may be removed continuously and auto-

matically by means of a centrifugal pump or intermittently by cross connecting two receivers.

The solids are drawn by the suction on to the face of the drum forming a uniform layer or cake. As the drum rotates this layer or cake adhering to the surface of the filtering medium emerges from the solution and suction being maintained, the mother liquor is drawn out of the cake.

When about to reach the topmost point of rotation (should washing be desired) the cake is subjected to wash water delivered from sprays arranged a few inches above the surface of the drum. A sheet of water is thus spread over the cake so regulated that no water runs back into the container. The suction causes this water to be drawn through the cake replacing the mother liquid held in its interstices, thus giving a most excellent wash. Should it be desired to keep the wash water separate from the original filtrate, the former may be led off separately through the specially designed valve to the proper receiving tank.

After passing the zone of sprays the cake is air dried before being discharged over the scraper. Just before reaching the scraper, however, the suction is automatically cut off from that particular compartment. At times it is advisable to apply a blast of air to the compartment at the point of discharge in order to open the pores of the filtering medium while the cake is being removed, thus leaving a clean medium with which to begin a new cycle. As the cake is discharged over the scraper in the form of a ribbon, it may be dumped into a receptacle and carried away at intervals or it may be fed onto an automatic conveyor and thus collected continuously.

The slurry in the filter container is kept in uniform agitation by means of a two blade agitator in the bottom of the container. These agitators are connected to the driving mechanism of the machine and require no separate connection or attention.

The machine is belt driven, with a heavy worm and gear connection to the drums on the opposite side from the vacuum line so that a steady even turning movement is maintained with little friction or wear upon the gears.

Should an especially dry cake be desired, or should a cake crack badly, the filter may be fitted with jacks or pressure shoes which subject the cake to compression after leaving the sprays.

Under such conditions the cracks are ironed out and the cake is under both suction and pressure, thus insuring an exceptionally dry product.

It is thus seen that during every revolution of the filter drum the solids are picked up, washed, dried and carried away continuously and automatically, no labor being required. The products are washed and discharged with no uncertainty and the machine registers a large capacity for the space occupied.

The rotary filter is made in many sizes ranging from a laboratory unit having a drum 1 ft. in diameter with a 6 in. face, up to a unit 8 ft. in diameter with an 8 ft. face. The filter is constructed with either a high or low container according to the properties of the solution to be filtered. With the high container the sides rise well above the hub of the drum, and with the low container the upper edge is just below the hub.

The high container is used for those solutions where the period of loading or filtering should be long compared with the period of washing, drying and discharge. The low container is for the reverse condition or where there is an exceedingly rapid filtering rate.

The drum of the filter may be constructed with enclosed ends for protecting the pipes leading from the compartments to the hub, should this be necessary.

The filter drum of wood and iron is supported by heavy cast iron spiders across which are bolted the thick wooden staves forming the drum proper.

The filtering medium is furnished according to the requirements of the slurry to be filtered. As usually required the compartments are encircled with a layer of cotton netting and upon this is placed the canvas.

The Industrial Filtration Corporation, which manufactures the Zenith filter, is also building a rotary hopper dewaterer, which could be used advantageously for dewatering the coarse coal prior to drying it in centrifugal dryers. The Zenith rotary hopper dewaterer, shown in Fig. 171, acts as an automatic draining board and dewaterer all in one and fulfills a long felt want for an automatic machine for dewatering coarse coal in a more effective way than can be accomplished with dewatering elevators.

The rotary hopper dewaterer consists of a series of hoppers or

deep compartments provided with filter bottoms and arranged radially about a central shaft and hub valve. Each hopper, below the filter bed, is connected to a valve by means of pipes of ample capacity. Provision is made in the valve for drawing off the mother liquor and wash water separately by suction (should it be desired to keep the two separate) and for pressure (when needed) for discharging the contents of the hoppers.

The design of the valve is such that as the drum rotates suc-

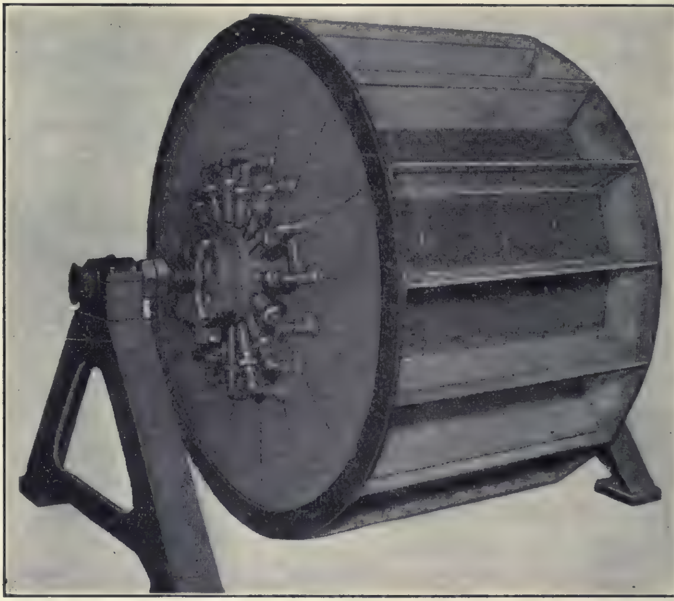


Fig. 171. Rotary Hopper Dewaterer

tion, pressure or cut off is applied automatically to each hopper as it reaches the proper point on the arc.

The rotary hopper dewaterer thus is in reality a series of simple filtering beds, which are connected so that they act continuously and automatically.

As the hoppers rotate they are charged from an overhead chute at about 30 deg. before they reach the top. Suction is applied during loading and in the course of filtration each hopper passes through an arc of approximately 120 deg. As each hopper passes somewhat below the horizontal, suction is cut off and a

puff of air or steam is introduced through the hub valve: the time of suction, cut off and pressure being automatically controlled.

This machine is provided with the same patented valve as is used on the Zenith rotary filter and possesses the same advantages arising from extra large pipe lines. Should the filtering medium wear out in one compartment, it is necessary to replace only the portion covering that one hopper. Of course the principal consideration that commends this machine is the fact that it is automatic and continuous in operation and requires no labor. It is replacing centrifugals, gravity and pressure machines in many places.

The Oliver Continuous Filter consists of a hollow drum supported on trunnions, and revolving with the lower part submerged in a tank. The filtering medium is on the outside of the drum and the inside is water-tight. The space between the two surfaces is divided into shallow compartments, each virtually forming an independent unit. Arranged radially in the hollow interior of the drum is a system of pipes connecting each compartment with the automatic valve, which controls the application of vacuum and the admission of compressed air or steam.

Material to be filtered is maintained at a certain height in the filter tank, and since a homogeneous pulp is essential, this is assured by a mechanical agitator, fitted into the tank. As the drum rotates, the filtering surface passes through every part of the agitated mass and a cake begins to build up on each compartment immediately upon entering the material, this process continuing until it emerges from the pulp. The liquid passes through the filter medium and the vacuum pipes to the automatic filter valve, which controls the whole cycle of operation. This automatic filter valve consists of a flat plate with a number of round ports corresponding to the compartments on the surface of the filter drum. The pipes for vacuum and compressed air connect to these ports. The valve chamber has annular ports corresponding to the different stages in the cycle of filter operation, such as forming, washing, drying and discharging of the cake. The face is ground to seat accurately with the valve plate and is automatically held in contact with it by the existing vacuum and by the action of a spiral spring when there is tem-

porarily no vacuum. An adjusting rod prevents the automatic valve turning, and insures maintenance of the desired conditions and adjustments.

The filter cloth is not applied separately to each compartment but one piece covers the entire drum, wire being wound spirally over it to hold the cloth firmly in place and protect it from wear. With this arrangement an unbroken cake of uniform size and consistency is constantly being formed. The vacuum is auto-

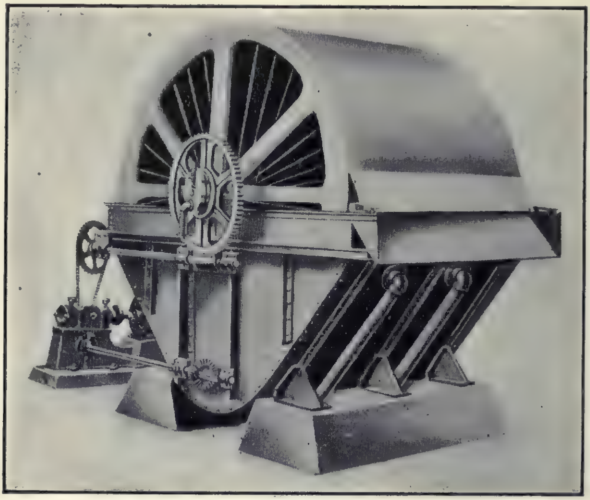


Fig. 172. Oliver Filter

matically shut off and just before reaching the scraper compressed air is automatically admitted to the compartments to loosen the cake. The scraper completely removes the cake and a perfectly clear filter surface enters the filter tank, thus starting another cycle. The discharged cake can be handled upon a belt-conveyor, or dropped directly into storage bins.

For maintaining a vacuum on the Oliver, either a wet or dry vacuum system is employed, but the latter is found the more efficient and economical in most cases. In addition to the dry vacuum pump, a vacuum receiver and a moisture trap are employed. A centrifugal pump is also used where a 30 ft. perpendicular drop from the vacuum receiver is not available.

Continuous and automatic operation is the keynote of Oliver

efficiency. Pulp is simply fed into the filter tank by gravity, though pumps may be used with good success, and nothing further is required except to arrange where the discharged water and coal are to be sent. It is advisable to have some one occasionally pass near the equipment to see that it is operating satisfactorily and to lubricate it; but it is not necessary to have an attendant on duty at all times.

The discharged coal contains 15 to 18 per cent. of moisture, and the capacity is from 500 to 1000 lb. dry weight of coal per sq. ft. of filter area in 24 hr. This varies, depending on the per cent. of solids in the filter feed, size of grains, etc. The

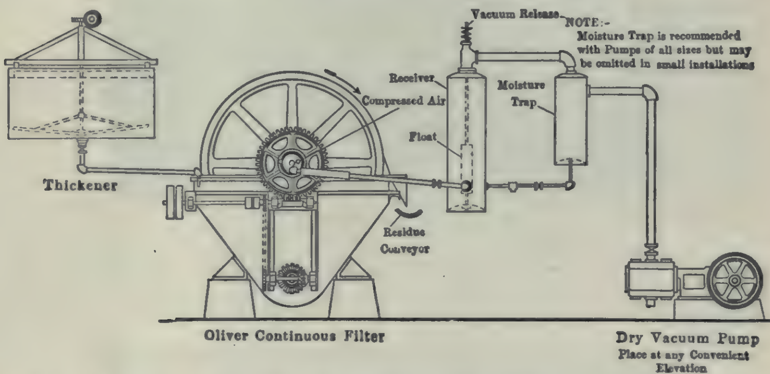


Fig. 173. Oliver Filtering and Dewatering System in Connection with Dor Thickener

standard type of Oliver filter for general use is shown in Fig. 172, while Fig. 173 illustrates a filtering and dewatering system in connection with a Dorr tank.

The *American Filter* shown in Figs. 174 and 175 is of a somewhat different design. It has a series of filtering disks instead of a filtering drum.

In the *American* filter filtration is carried on by applying a vacuum to the discharge, thus inducing a flow of filtrate. The filter elements—heavy screen filter discs of sectionalized construction—are mounted perpendicular to a horizontal shaft provided with longitudinal passageways which connect to all leaf sectors in the same phase of rotation. The lower half of the filter leaves dip into the sludge or pulp which is held in a pan

construction which provides, on the discharge side of the filter, individual pans for each leaf so that solids drop down between

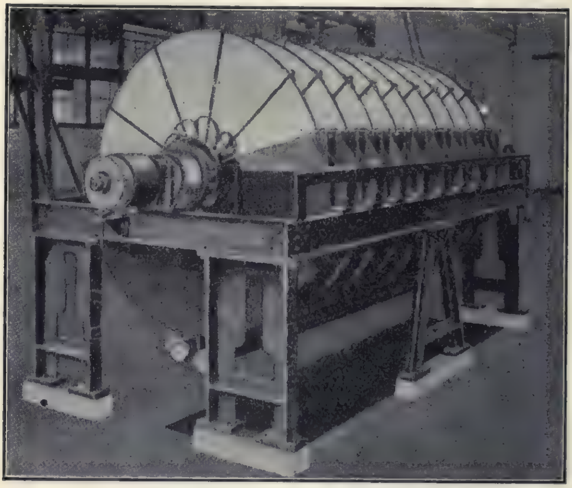


Fig. 174. American Filter

pans into whatever type of conveyor is provided. The discharge from the filter is controlled by a rotating valve which provides

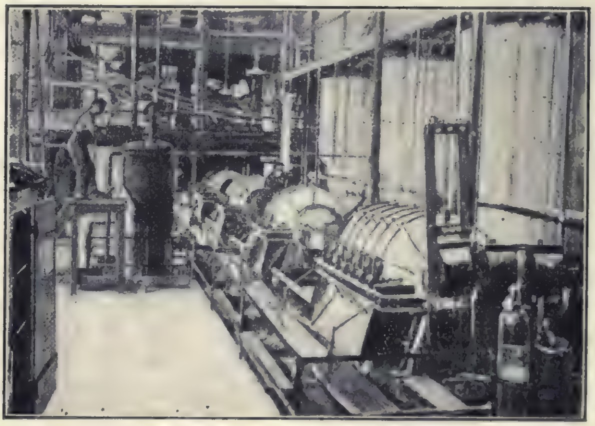


Fig. 175. American Filter Installation

for separate discharge of filtrate and effluent wash-water. A compressed air connection is also provided for inflating each filter

leaf section as it starts to pass the scraper. When the solids are to be washed the filter is provided with a spray washing mechanism. The operation of the filter is continuous, each leaf section in turn passing through a period of filtering, washing, drying and discharging.

The special design permits installing a much greater filter area in the same floor space than is possible with any other type of suction filter. Huge diameters are unnecessary and the filter requires little head room. The filter cloth is thoroughly cleaned at

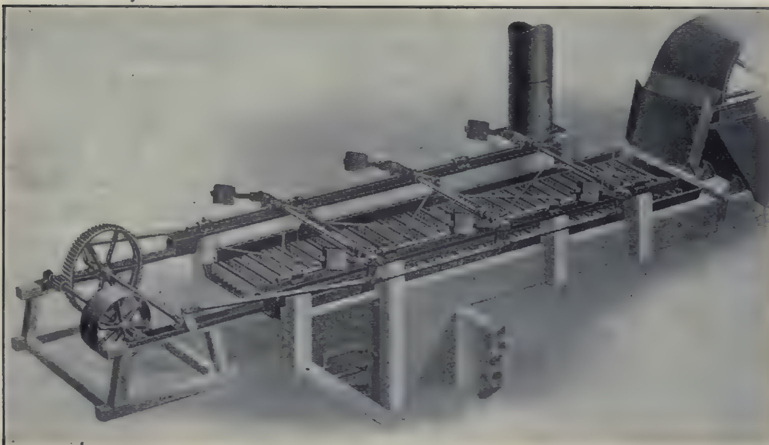


Fig. 176. Lowden Dryer

each revolution, thus maintaining a maximum capacity per unit of filter area. Ample drainage is provided from the filter leaves, thus insuring a dry cake. Any single leaf section may be easily removed and recovered, thus eliminating long shut-downs for redressing.

If it should be found desirable to dry the sludge to less than 15 per cent. of moisture a heat dryer could be installed in connection with the continuous filters. Such a machine, which is now used extensively for drying the flotation concentrates in ore dressing mills, is the Lowden patented heat dryer illustrated in Fig. 176.

The Lowden patent dryer was designed especially to meet the urgent necessity for a machine capable of handling extremely

fine material such as would suffer excessive dust losses in dryers of other types, also material in a plastic condition such as would be almost impossible to feed to most other dryers.

The relatively low efficiency of the pre-existing hearth-type dryers has been largely overcome in this machine, and it offers advantages over any other on many classes of work.

It consists of a hearth composed of heavy cast iron plates heated from beneath by the gases of combustion from a fire box or by waste heat. The material is normally delivered to the cooler end of the hearth and is slowly advanced to the hotter discharge end by a series of rabbles which effectively break up and plow the material, thus exposing it thoroughly. It is the peculiar and characteristic action of its rabbling mechanism which sharply distinguishes this device from all other analogous dryers and makes it successful where others fail. The rate of transmission of heat through cast iron is as rapid as can be absorbed by the material in the vaporization of moisture, if the cast iron plates can be kept free from a layer of insulating material. This the raking mechanism of the Lowden dryer accomplishes, and the objections to the grasshopper dryer in that respect are absent.

The possibility of delivering large batches of insufficiently dried material, which is always present with the chain rabbled dryers, is also absent, owing to the reciprocating action of the rakes. Any material that adheres to the rabbles falls back upon the hearth in practically the same place as that from which it was lifted.

The Lowden patent dryer is built in various sizes for capacities of 10 tons up to 100 tons per 24 hr., the size for any given capacity depending upon the amount of moisture to be eliminated, and in lesser degree upon other factors. The speed is low, two cycles or less per minute, and the power required is small.

In Fig. 177 one of the many possible arrangements of the Lowden dryer in connection with a continuous filter in a unit for drying sludge is illustrated.

The thickened sludge is drawn from the Dorr thickener through "D" by a diaphragm pump and flows at "T" into the sludge tank of a continuous filter, from which, after dewatering,

it falls at "F" upon the hearth of the Lowden dryer, being discharged at "G."

For the sake of clearness, the illustration below shows the equipment arranged in a line, but ordinarily it would be so disposed that the coarse concentrates bin would be near the discharge of the dryer.

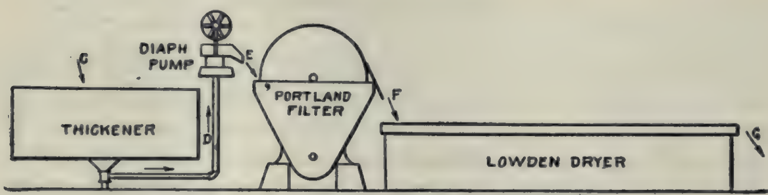


Fig. 177. Installation of Lowden Dryer in Connection with Portland Filter and Dor Thickener

The installation of the Lowden dryer offers no special difficulties, either in feeding or disposition of the dried product. It may be fed direct from a filter, as shown, or from a conveyor, and may discharge upon a conveyor, directly into a bin or car, or into the boot of an elevator.

CHAPTER XXXI

PYRITE RECOVERY

Pyrites are found in coal either in the form of sulphur balls or in the shape of fine scales and grains disseminated throughout the mass. The separation of the pyrites from the coal does not offer any appreciable difficulties on account of the great difference in the specific gravities of the two materials. The specific gravity of pyrites is from 4.9 to 5.2, and even the slate carrying fine flakes of sulphur has a specific gravity of only slightly below 3.

A more serious problem is how to prepare the pyrite if it occurs in considerable quantities. This can be best accomplished by wet separation, and the following methods are used:

1. If the pyrite appears in large pieces or is contained within large pieces of slate, hand picking and subsequent separation into pure pyrite and mixed products is advisable.

2. Instead of hand picking, the heavy pyrite can also be recovered in coarse coal jigs, which have an auxiliary screen sloping toward the center. The pyrite is removed from the lowest point of the screen through a kettle valve. In some instances nut coal jigs have a separate bed for the separation of the pyrite and three products are made in the following manner: (a) Pyrites through an artificial bed and screen into the hutch; (b) slate through a slate gate, located at a somewhat higher level, and (c) clean coal overflowing in front of the jig.

3. Rewashing of the refuse is a method especially advisable for large size pyrites.

4. For fine pyrite the methods under (b) and (c) can be adapted by using a fine coal jig.

5. If the pyrite is so finely disseminated that it partially goes over with the sludge, it settles out in the clearing basins and the sludge rich in pyrite can be treated on tables. On account of the small quantities of pyrite in coal the economic results gained

by its recovery usually lie within narrow limits. The great price fluctuations of sulphur are also discouraging, and under normal conditions a lasting profitable operation is at best doubtful.

C. H. Cady, geologist of the Illinois Geological Survey, has studied the occurrence of pyrite thoroughly and has classified the pyrite found in Illinois coal as follows: [1]

"Pyrite has been observed to have the following habits of occurrence: As brassy, massive, metallic-appearing mineral without apparent crystalline structure or form; as a crystalline mineral; as a brown or gray mineral without metallic luster or apparent crystalline character, this form being commonly laminated; and as impregnations in a very fine state and probably crystalline. The material occurs in the following common forms: As balls and lenses of a well defined shape and easily separable from the surrounding coal; as balls and lenses with the outer parts more or less ramifying into the surrounding coal and hence not easily separated from it; as a fine leaf mineral in finely divided state lying along innumerable joint cracks in isolated patches of the coal; as typical vein filling, especially in 'horsebacks'; as replacement of limestone, forming 'niggerheads' in the roof shale, and in other limestone masses found associated with the coal; as impregnations of mother coal and of the clay filling of horsebacks; as balls in the floor clay; as plates or sheets commonly found in the partings between benches; as facings in joint cracks, commonly very thin plates; and as rosettes in the laminations of the black fissile shales found above some of the coals.

"The habit of occurrence of the pyrite seems to bear relation to the form. Pyrite in balls and lenses easily separated from the coal is apparently nearly always of the brassy, massive variety. The lenses and balls of indefinite boundary are commonly the gray, stony variety; this variety, at least, seems always to have an indefinite outline. The plate and sheet pyrite is variable in its habit, but pyrite of metallic appearance seems to be the most common variety. Facings are composed of the bright pyrite. Vein fillings, the nodules in the fireclay, the rosettes in the roof slate and probably the impregnations of the clay fillings of horsebacks and of mother coal are all of a crystalline nature. Pyrite which replaces limestone takes on the form and texture of the original rock.

"The ease with which pyrite is separated from coal at the face, the tipple or the washery depends largely upon the form of occurrence. As between the stony, crystalline and massive bright varieties there is practically no distinction so far as relative ease of recovery is concerned. The most easily separable pyrite is that occurring in balls and lenses of the brassy variety. It is plainly seen and its outline clearly defined, so that it is usually broken out by the miner at the face. The pyrite occurring in the nigger-

[1] "Valuable Pyrite in Illinois Coal Beds," by G. H. Cady, geologist in charge of coal studies, State Geological Survey Division, Urbana, Ill. (*Coal Age*, Vol. 16, No. 4, 1919.)

heads and in limestone lenses or masses in the coal or near the boundary of the coal and the roof rock are also readily discarded. Next in relative ease of removal is the plate or sheet pyrite, provided the plates are of sufficient thickness to withstand the shattering effect of mining. If ½ in. or more thick, the plates can usually be removed without difficulty from the coal, in pieces sometimes more than a foot wide. As the seam commonly parts at the pyrite band the material can be removed rather easily. Small pieces, however, commonly remain in the coal. If the plates or sheets are thin, the proportion that is recoverable is small, since it is commonly so badly shattered in mining that removal by the miner is practically impossible. Such pyrite as this could be largely removed by washing the finer sizes of coal.

"The removal of the brown, or gray, banded pyrite in the mine is attended by more or less difficulty. It is not quite as readily seen as the bright variety, for not uncommonly it is rather dark colored by reason of the presence of a large quantity of what appears to be carbonaceous matter. Then, also its outlines are indefinite. To remove this variety of pyrite much coal must, in general, be wasted if the entire mass of the lens is to be recovered. Coals having this form of pyrite in large quantities are almost sure to have a rather high pyrite content as shipped, unless all the coal is washed. If the larger sizes of coal were hand-picked at the tipple, large amounts of this material would probably be effectively removed. Pyrite present as facings is practically impossible of removal by any method of hand-picking except where, as in some rare localities, the facings become so numerous as to be practically a mass.

"In some of the better Illinois coals pyrite occurs only as facings or as leaf pyrite. The removal of some of this impurity can be accomplished by crushing and washing the finer sizes, but it is probable that the actual amount of pyrite that could be thus removed would be negligible and would only in small degree affect the selling value of the coal.

"Masses of leaf pyrite are commonly not discarded; although the mass may have a bright appearance, the actual amount of pyrite present is small. This is indicated by the fact that such a mass of coal filled with particles of leaf pyrite weighs but little more than pure coal. Furthermore, such pyrite is difficult to separate by washing, the small flakes of mineral remaining suspended and floating off with the coal. The problem of separating such pyrite from coal is yet to be solved.

"The vein pyrite coal in Illinois rarely exceeds ½ in. in thickness. Its occurrence is practically restricted to the horseback fissures such as are found to be especially numerous in the No. 5 bed. The coal adjacent to such fissures is commonly well impregnated with pyrite in a finely divided state so that the entire mass is very hard. It is the common practice to entirely discard the mass of coal attached to the sulphur 'spar,' as it is called, for it is usually thoroughly impregnated with pyrite. The miner receives extra pay for the removal of this material so that impurity of this sort does not commonly reach the top, except where the 'spars' are thin.

"Clay veins also are commonly rich in a finely divided pyrite that is dis-

seminated throughout their mass and reaches out into the adjacent coal. This pyrite with the attached coal is discarded just as the pyrite and coal in sulphur 'spars' is thrown away. In many mines the removal of the horsebacks is a cause of considerable waste, and in some instances serious consideration could well be given to the problem of its elimination in, at least, a large degree.

"The impregnation of mother coal by pyrite gives a very hard black material with the general appearance of mother coal but with a slight golden tinge. The material is very hard. The substance is commonly called 'blackjack' by the miners, though it is possible that all the 'blackjack' of miners is not pyritized mother coal. The material is nearly as difficult to cut as the gray or brassy pyrite, and where it lies in relatively large masses is readily discarded. Smaller masses, however, especially if imbedded in large masses of coal, are less easily removed. 'Blackjack' commonly sticks rather tightly to the surrounding coal and the removal of pieces less than a foot in length and an inch or two thick, except as they occur along partings, does not seem to be common practice.

"The sulphur balls found in the floor clay and the pyrite rosettes found in the roof shale do not commonly get into the coal as shipped. They are rather interesting occurrences but of no special importance commercially, except that clays with these sulphur concretions are not adapted for burning."

Professor E. A. Holbrook carried on a series of tests for the purpose of determining the best method of recovering the pyrites from coal by crushing and washing.[1]

"Since the hand-picked pieces of pyrite from coal range up to several inches thick and more than a foot square, and since pieces of coal tend to adhere to the lumps, hand-picking in general will not produce a high grade product. It is true that by hand-picking and hammering the larger lumps may be freed of coal sufficiently to produce a salable product, but this method involves the waste of the large amount of pyrite which occurs in pieces smaller than 2 in. in diameter, or of a size too small to permit hand-picking to be done profitably. It should be remembered also that the fine pyrite is of greater value per ton than the coarse material.

"Since the specific gravity of the pyrite is high (4.7 to 5.1) as compared with that of coal (1.3), washing by a process involving jigging or agitation in water causes the heavy mineral to sink rapidly while the light material may be drawn off at the top. This principle of separation is used in the ordinary jig.

"With the purpose of devising some simple washing or ore-dressing process to effect a separation of the pyrite from its adhering coal, the Department of Mining Engineering of the University of Illinois has under-

[1] "The Utilization of Pyrite occurring in Illinois Bituminous Coal," by E. A. Holbrook. Circular No. 5, Engineering Experiment Station, University of Illinois, Urbana, Illinois.

taken a series of tests, with various samples of pyrite. As a result of these experiments, an arrangement of machines has been worked out, and the power required and the cost of operation have been determined for a simple plant capable of preparing nearly pure pyrite on the one hand and commercial coal on the other.

"The mining laboratory at the University of Illinois is equipped with rock crushers, breakers, and rolls of several different kinds, installed in such a manner as to make possible the determination of the best method of crushing any ore or coal to the size necessary for subsequent treatment. Included in this equipment are screens of the revolving or trommel type, and shaking and vibrating screens to divide the crushed material into several sizes required for further treatment. There are also jigs of the plunger, Hartz or Lührig type together with jigs of the basket or Stewart type. These jigs separate the valuable mineral from the refuse. In addition special machines in the form of concentrating tables are installed for special treatment of fine or small material, that is, material too small to be successfully handled by jigs.

"Preliminary tests were made by crushing the crude pyrite to various sizes in different types of crushing machinery such as breakers, rolls, and pulverizers, and by comparing the various samples of pyrite to determine the extent to which separation of pyrite and coal had been effected. Sizing tests were made on various kinds of screens and separation of these products was effected by different types of jigs, washers, and concentrating tables. The Delamater float and sink test machine was particularly useful in determining roughly the possibilities of separation of various sizes of mixed coal and pyrite. The possibility of separating pyrite from coal by a strong electric magnet was also tried, but under the influence of a 6-ampere 40-ohm electric magnet installed in a Dings electromagnetic separator, the results were negative. Without describing in detail the various tests, it is sufficient to give an outline and to present the average results of those tests which proved most successful, and which gave a high percentage of recovery at a low or reasonable cost.

Summary of Tests

"*Machinery Required.* The tests performed lead to the conclusion that the practical separation of pyrite from Illinois coal for the purpose of obtaining a commercial grade of pyrite, with coal as a by-product, presents no difficulty when performed by crushers, screens, and concentrating machines adapted to ordinary ore-dressing work. The chief problem is to secure a plant of the greatest simplicity and of the lowest cost. At the same time it should be of good capacity and should yield a high percentage of recovery of the pyrite.

"*Percentage of Recovery.* The experiments from which the data resulted indicate that a simple plant will recover about 81 per cent. of the pyrite in the coal, and that if the middlings product from the jig is crushed and retreated, this recovery can be increased to about 87 per cent. This pyrite

will average more than 40 per cent. of sulphur and may be sold directly to chemical or to fertilizer companies. The coal recovered as a by-product is not greatly inferior to ordinary screenings."

ESTIMATED OPERATING STATEMENT OF A PYRITE PLANT OF A CAPACITY OF 50 TONS PER 8 HOUR DAY

Debit		Credit	
50 tons of hand-picked pyrite at $1.35	$ 77.50	Coarse pyrite, 24,000 lb., 45 per cent. sulphur at 15 cents per unit: $6.75 per ton	$ 81.00
Interest and depreciation on plant. Investment of $18,000 at 20 per cent. per year	12.00	Pea pyrite, 22,000 lb., 45 per cent. sulphur at 15 cents per unit	74.25
Labor, 5 men at $3	15.00	Fines, 6,510 lb., 41 per cent. sulphur at 15 cents per unit	20.02
Supplies and renewals	15.00	Extra pyrite if middlings are retreated: 4,290 lb., 43.5 per cent. sulphur	13.99
Power, 50 h.p.	10.00	Coal, 35,231 lb., at $1 per ton	17.62
	$129.50	Loss (allowing for coal in middlings as loss), 8,325 lb.	
			$206.88
			129.50
		Profit per day	$ 77.38
		Profit per ton of raw pyrite	$ 1.55

TABLE 51

Estimated Operating Results. An effort has been made to forecast the results of operating a 50 ton per 8 hour day pyrite plant, under conditions comparable to the average met at Illinois mines, where pyrite is to be found in sufficient quantities to warrant recovery. The summary presented in Table 51 is based partly upon estimated figures, especially with reference to the cost of crude pyrite as laid down at the plant. The figures given for the value of the product are based on a price of 15 cents per unit of sulphur. In nearly every case, the estimates are believed to represent maximum costs and conservative selling prices.

Method of Operation. Fig. 178 is a diagrammatic illustration or simplified flow sheet of the treatment plant recommended as a result of the tests performed. The successive steps believed essential to the complete treatment of such pyrite are shown. Fig. 179 shows the same flow sheet with percentages of recovery

attained at each part of the process. This indicates results which might be accomplished in practical work. Owing to the difficulty experienced in regulating machines for the relatively small tonnage treated in laboratory work, it is believed that in every case, commercial practice on a large scale would result in

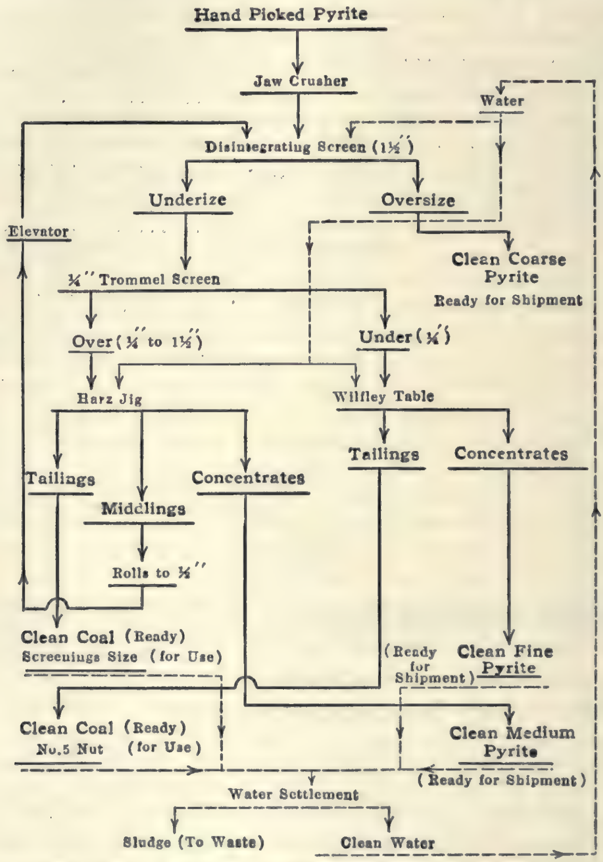


Fig. 178. Flow Sheet for Pyrite Recovery Plant

higher recovery than is indicated by this outline. The tonnage is based on a plant capable of treating 50 tons of crude hand-picked pyrite per 8 hour day, as this is believed to represent the largest plant needed by one mine or even by several mines combined.

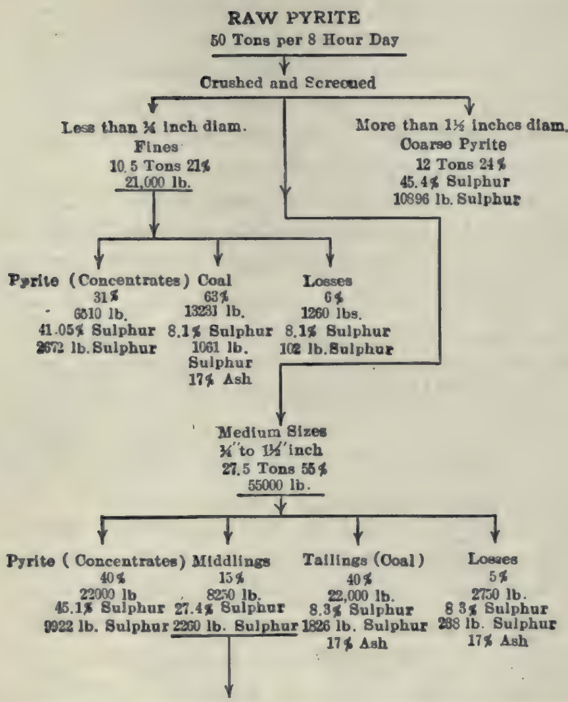


Fig. 179. Flow Sheet for Pyrite Recovery Plant Showing Percentages of Recovery

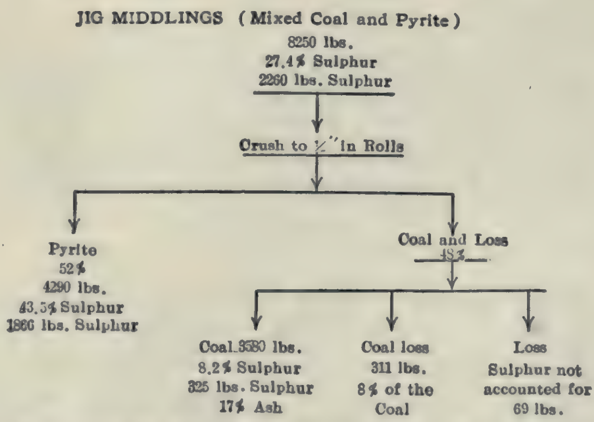


Fig. 180. Flow Sheet for Recrushing the Jig Middlings

Fig. 180 is a diagram which indicates the possibilities of recrushing the middlings product obtained from the second compartment of the jig, then screening it through the ¼ in. trommel screen, and allowing it to pass either to the jig or to the concentrating table, according to its size. In this way the recovery can be increased by about 6.4 per cent.

Table 52 shows the amount of percentage of recovery or loss of the pyrite in each operation of the process, based on sulphur content as determined by sampling and by analysis of each of the products recovered.

Flow Sheet Reduced to a Basis of Sulphur Content, Showing the Amount of Sulphur in Each Product Based on the Output of a Plant Having a Capacity of 50 Tons per 8-Hour Day

Product	Name	Size	Sulphur Per Cent.	Sulphur Content Lb.*	Sulphur Recovered Lb.	Per Cent. of Total Sulphur Recovered or Lost
Coarse (Screen) Concentrates	Lump Pyrite	Above 1½ in. ring	45.4	10896	10896	37.6
Fine (Table) Concentrates	Fine Pyrite	Under ¼ in.	41.05	2672	2672	9.2
Medium (Jig) Concentrates	Pea Pyrite	1½ in. to ¼ in.	45.1	9922	9922	34.2
Total					23490	81.0 Recovery
Middlings from Medium Concentrates		Crushed to ½ in.		2260	1866	
Total with Middlings Added					25356	87.4 Recovery
Fine Coal	No. 5 Nut	Under ¼ in.	8.1	1826		
Coal from Jig Overflow	Screening Size	1½ in. to ¼ in.	8.3	1061		
Loss (Jig)	Coal	Estimated	8.3	102		
Loss (Table)	Coal	Estimated	8.1	238		
Loss (Middlings)	Pyrite	Not acct. for	69 lb.			
Total Sulphur in Original Product				28977		

* 28,977 lb. of sulphur from 50 tons of material amounts to 28.98 per cent. of sulphur in original crude hand-picked pyrite (assuming all sulphur to be in the form of pyrite). For pyrite containing 53.4 per cent. of sulphur, the total pyrite content of the crude pyrite would be 54,264 lb., or 54.26 per cent. of pyrite, and, therefore, the content of coal and contained ash and shale would be 45.74 per cent. The total recovery from disintegrating screen, jig, and table on the crushed crude pyrite was 81.0 per cent. of the total pyrite or 23,490 lb. of sulphur from the 28,977 lb. contained in 100,000 lb. of crude pyrite. If the middling product from the jig is recrushed and treated, the recovery is increased to 87.4 per cent., or 25,356 lb.

Table 52

The coal produced as a by-product contains about 8 per cent. of sulphur, a part of which is in the form of pyrite. In commercial operations extending over considerable periods this loss of pyrite could be decreased, as it is largest when starting and while shutting down the machinery. These operations occur fre-

quently in experimental runs. The amount of coal recovered as a by-product is considerable, the tests indicating 38,811 lb. per day from the plant and product under discussion, or from 18 to 20 tons. It should be remembered that this coal is of screening size, and that its purity depends largely upon the care with which the pyrite is removed during the process of cleaning.

The Tests and the Results. In the final tests the pyrite as received (about a ton in weight) contained from 25 to 28 per cent. of sulphur, or about 50 per cent. by weight of pyrite. The other 50 per cent. of the mineral consisted of coal adhering to the lumps and intermixed with the bands of pyrite. The material had been hand-picked at a tipple preparing No. 7 coal in the Danville district. The lumps, including the adhering coal, were as large as 6 or 8 in. in thickness and were often a square foot in area. This material was first put through an ordinary rock breaker. The rock breaker in the laboratory is of the Gates gyratory type, but from tests made with a Blake type rock breaker it is believed that the latter type will be equally satisfactory and probably cheaper in first cost. Attention is here called to the fact that ordinary coal-crushing machinery is not suitable for crushing raw pyrite. The pyrite is extremely hard and only breakers designed for hard rock should be used. Breakers designed for soft material do not possess adequate strength, and the wear will be excessive if used on this class of material.

The breaker was set with a throat opening, or discharge, about 1½ in. wide, and although the pieces discharged through this had a thickness of not more than 1½ in., the area of some of the lumps was several square inches in extent, owing to the tendency of the pyrite to break into flat slabs. Examination showed that this breaking process caused a large portion of the lump pyrite to separate from the adhering coal. The coal itself tended to break into cubical pieces. Also the coal, because of its brittleness, generally broke up into finer sizes than the pyrite.

After breaking, the large lumps of pyrite had only small bits of coal adhering to them. Thus it was decided to screen this material in an attempt to secure a coarse pyrite which would be sufficiently clean for the market. The crushed material was put through a revolving or trommel screen having round-hole open-

ings of about the same diameter as the opening in the rock breaker. Since the coal tended to break into cubical pieces while the pyrite tended to break into flat pieces, it was thought that a separation could be made of the two by simple screening alone. This expectation was borne out by results obtained. Later, steel lifters were introduced in the revolving screen. During screening these lifters caused the material to be carried to the top of the screen and to be dropped several feet. The impact from this fall served to break any large coal so that it passed through the screen, and it also freed the pyrite of any small particles of adhering coal. It was shown also that lump pyrite may, if desired, be further cleaned by screening the material while wet, that is, by introducing sprays of water into the screen. The rubbing action of the wet material against the screen serves to loosen most of the specks of coal remaining on the coarse pyrite so that they may pass through the screen. The greater the diameter of the screen, that is, the greater the length of fall of the particles after having been lifted, the freer is the oversize, or clean coarse pyrite of coal impurity.

The Size of Screen Holes. As previously mentioned the largest size of screen opening was about a 1½ in. round hole. This screen is not unlike the Bradford disintegrator which is in common use for cleaning coal to free it of lumps of shale, pyrite, sticks of wood, bits of iron, and other impurities. The result of this screening was the production of 21 per cent. of the total amount treated as clean lump pyrite of 1½ in. minimum size, and of an analyzed purity which in all the tests ran more than 40 per cent. sulphur and in some as high as 45.4 per cent. By this simple process of crushing and screening, it was possible to produce 37.6 per cent. of the pyrite immediately in the form of a clean marketable product.

The material passing through the 1½ in. holes of the disintegrating screen entered a small trommel or revolving screen having a screen plate with holes about ¼ in. in diameter. The purpose was to separate the material smaller than 1½ in. into two sizes, one of which should contain all sizes between 1½ in. and ¼ in., and the other, all sizes below ¼ in. If desired, the same results could be obtained by adding an outer screen plate with

¼ in. round holes to the disintegrating screen, that is, by making it a compound concentric screen. It is probably more satisfactory to use separate screens, especially if the matter of making repairs easily is considered. Where all the sizes less than 1½ in. in diameter were washed or jigged together, the separation of the pyrite from the coal was incomplete, especially in the fine sizes below about ¼ in. Jigs are not well adapted for the treatment of these fine sizes, therefore separate treatment of the material below ¼ in. should be made on a special concentrating table designed for fine material.

Of the amount falling through the holes of the disintegrating screen, 70 per cent. was larger than ¼ in. This material larger than ¼ in. in diameter and smaller than 1½ in. was sent to a two-compartment Hartz or Lührig plunger jig. The jig used in the laboratory is of the two-compartment commercial type and is of half dimensions, capable in every way of giving commercial products. From this jig three products were obtained. No. 1 was clean pyrite product from the first compartment draw-off which amounted to 22 per cent. of the total feed or 34.2 per cent. of the total pyrite in the mineral. The sulphur content of this product ranged from 42 per cent. to 46 per cent. No. 2 was material from the second compartment amounting to 7.8 per cent. of the total pyrite or 2.3 per cent. of the amount of feed. This material was a true middling product; that is, it consisted of pieces of pyrite and coal which had not been freed from each other. In other words, the weight of any piece lodging here was not quite sufficient to cause it to settle in the first compartment, and still the piece was not light enough to allow it to overflow the second compartment. No. 3 was the overflow material from the second compartment which was found to be practically clean coal. In the preliminary runs some pieces of pyrite were observed in this product, but after a few trials to get the correct adjustment of the jig, no difficulty was experienced in obtaining a coal comparable with the ordinary screenings furnished by Illinois coal mines.

Middlings such as were noted in the second compartment were not in condition to be marketed since their sulphur content was only 27.4 per cent. In commercial practice, if the quantity of

these middlings is sufficient to warrant it, more nearly complete separation may be accomplished by recrushing to a finer size and passing again through the disintegrating screen.

In coal washing work in Illinois little attention has been paid to material under ¼ in., largely because material of this size usually contains an excess of refuse and because it does not readily dry out or free itself of water. In pyrite washing, however, conditions are different. A considerable portion (21 per cent.) of the material crushed in the rock breaker will be found to be under ¼ in. in size. Since this material contains about 42.2 per cent. of pyrite and since this fine pyrite has become more valuable than the larger sizes, some form of modern ore-concentrating table should be used to separate pyrite from coal in these sizes. No difficulty will be found in freeing these sizes of pyrite of water. In the experimental work, a laboratory concentrating table of half commercial dimensions was used. The material fed to the table in the test runs was effectively separated into fine pyrite, containing on the average run more than 40 per cent. sulphur, and fine coal which might be added to the coal obtained from the jigs. As a rule, the handling of quantities of such fine coal presents some difficulty because of the problem of removing the water from it after washing.

Losses. The tests indicate either 81 or 87 per cent. recovery of the pyrite as shown by sulphur analysis. They therefore show a loss of 19 and 13 per cent., respectively. This seems to be a satisfactory metallurgical recovery for such a washing process, especially since the effort has been to employ the simplest sort of machinery.

Probably 5 to 20 per cent. of the coal in the smaller sizes will be lost during the process, largely by passing off as sludge in the water. Analyses indicate that this sludge is too impure to be used as coal. Not only is it very fine, but much of the clay or shale impurity which is intermixed with the coal has softened under the influence of the water and passes off with the sludge.

Water Supply. In any wet concentration process using jigs and concentrating tables, the question of an adequate supply of water is important. Water is used in spraying the rock in the breaker for the purpose of keeping down dust; it is used in the disintegrating screen to assist in the cleaning; and from this

point the material under 1½ in. in size is practically flowing in a stream of water. The jig and concentrating table both require water, for the feed, for the separating process, and for carrying away the separated products. By the use of perforated elevators and draining bins it is possible to recover all the water draining from the products in a central pond or sump and to use it over and over by pumping. The sediment or sludge in the water consists largely of fine coal and clay, since the pyrite is too heavy to pass off with the water except in the smallest sizes. The settling pond or sump common at Illinois coal washeries can be replaced to good advantage by a large round settling tank 20 or 30 ft. in diameter equipped with a uniformly horizontal rim over which the water may flow.

The sludge water from the plant should enter this tank at the center and under the surface of the water. Passing toward the rim of the tank, the sludge will settle to the bottom and the water, sufficiently clean to be reused, will overflow the rim and may be directed into a small sump from which it may be pumped back to the plant. The tank should be equipped with a steeply sloping bottom so that the accumulating sludge may be easily removed. A settling tank of similar character, which has been used for many industrial purposes, is the Dor settling tank. The importance of fairly clean water in the operation of a plant of this kind may be readily understood since water used several times without settlement of the sludge often contains as much as 3 per cent. of solids in suspension. Such water, draining from the washed pyrite, will contaminate it by depositing solid material on its surface and will thus lower the sulphur percentage of a product otherwise satisfactory.

In cooperation with Wilbur A. Nelson, E. A. Holbrook made further tests, under the direction of the Bureau of Mines, to determine the value of pyrite found in Tennessee [1] coals. The report on these tests outlines the known coal pyrite resources of Tennessee and details tests made at Urbana, Ill., on crude pyrite from the mines of the Bon Air Coal and Iron Corporation, to learn if the material could be mechanically treated to produce a pyrite of commercial purity.

[1] "Coal Pyrite Resources of Tennessee," by E. A. Holbrook and Wilbur A. Nelson. *Coal Age* (Vol. 15, No. 24, 1919).

Outside of the large deposits of pyrite and pyrrhotite in east Tennessee in the Ducktown region, the state has an additional source of pyrite from certain of the coal seams of the Cumberland Plateau.

The mines in the Bon Air-Clifty district all contain pyrite in the form of bands, nodules and kidneys, which are easily separated from the coal and can be recovered as a byproduct. It is estimated that the amount of pyrite, if all is recovered, from the

Original Material, 422 lb. 32.68% Sulphur
Trial Test

Crushed to ¾-in. Maximum Size

Jigged Without Sizing on a 2-compartment Jig

1st Screen Bed Concentrates	1st Hutch Concentrates	2d Bed Middlings	2d Hutch Concentrates	Tailings (Coal)	Loss
156 lb.	24 lb.	119 lb.	26.0 lb.	63.0 lb.	34 lb.
37.0%	5.7%	28.2%	6.1%	14.9%	8.1%
43.1%S.	44.0%S.	36.7%S.	36.1%S.	5.3%S.	....
				19.8% Ash	....

Recrushed to ¼-in. size

Butchart Concentrating Table

Concentrates	Middlings	Tailings	Loss
85 lb.	8 lb.	19 lb.	7 lb.
71.4%	6.7%	16.0%	5.9%
41.6%S.	30.1%S.	12.3%S.	
		32.1% Ash	

NOTES—1st Screen Bed Concentrates means the coarse concentrates saved on the 1st bed of the jig.

2d Hutch Concentrates means the fine concentrates passing through this screen and saved at the bottom of the jig.

Middlings means a product of pieces containing part coal and part pyrite which have to be crushed finer before any separation of clean pyrite can be made.

FIG. 181. FLOW SHEET OF COAL PYRITE CONCENTRATION MATERIAL FROM EASTLAND MINE

mines in this district when operating at full capacity will be at least 50 tons daily. This estimate was made to include all the mines operating on the Bon Air branch of the Nashville, Chattanooga & St. Louis Railway.

Clean samples of pyrite from some of these mines gave the following analyses:

Carola Shaft, Bon Air, Tenn.	47.0 per cent. sulphur
Braeburn Mine, Eastland, Tenn.	47.6 per cent. sulphur
Ravenscroft Mine, Ravenscroft, Tenn.	46.4 per cent. sulphur

The mines on the Monterey branch of the Tennessee Central contain pyrite in a recoverable form. This pyrite is similar to that from the Bon Air district, on which tests were made. It is estimated that probably 40 tons of pyrite a day could be recovered from this district. Clean samples of pyrite were taken from some of these mines, which gave the following analyses:

Fentress Coal Co., Wilder, Tenn.	46.4 per cent. sulphur
Peacock Mine, Big Mountain Coal Co., Obey City, Tenn., Weather surface pyrite	46.1 per cent. sulphur

Hand cobbed samples of pyrite were taken from these mines, so as to show the approximate percentage of sulphur in carload lots of unwashed pyrite as it would be shipped from the mines if no plant for treating the pyrite was installed. The following analyses show these results:

Carola Shaft, Bon Air, Tenn.	43.88 per cent. sulphur
Braeburn Mine, Eastland, Tenn.	46.40 per cent. sulphur
Ravenscroft Mine, Ravenscroft, Tenn.	43.72 per cent. sulphur
Clifty Mines, Clifty, Tenn.	42.72 per cent. sulphur
Fentress Coal Co., Wilder, Tenn.	45.08 per cent. sulphur
Peacock Mine, Big Mountain Coal Co., Obey City, Tenn.	40.36 per cent. sulphur
Brier Hill Collieries, Crawford, Tenn.	36.08 per cent. sulphur

The pyrite from the Fentress Coal Co. has been shipped to an acid manufacturer for some time, with satisfactory results to both the mine owners and the acid makers. The pyrite from all these mines, with the probable exception of the Brier Hill collieries, would be satisfactory for acid making after having been crushed and cleaned.

Pyrite is also found in a few of the mines in the Tracy City-Coalmont district, but not in sufficient quantities to justify saving and shipping. In the northeastern Tennessee coal field some pyrite occurs but no detailed investigation was made of this area.

About Sept. 1, 1918, two shipments of crude coal pyrite were received at the laboratory of the U. S. Bureau of Mines, University of Illinois, Urbana, Ill., from the Eastland and Ravenscroft

Original Material, 809 lb. Sulphur Analysis, 40.5%

Crush to ¾-in. size

1st Bed Pyrite	1st Hutch Pyrite	2d Bed Middlings	2d Hutch Middlings	Waste Tailings	Loss
214 lb.	38 lb.	268 lb.	58 lb.	173 lb.	57 lb.
*26.5%	4.7%	33.2%	7.2%	21.4%	7.0%
45.2%S.	44.0%S.	43.9%S.	43.4%S.	26.3%S.	
				45.3%A.	

Crush to ¼-in. size

308 lb.

Treat on a Concentrating Table

Clean Pyrite	Middlings	Tailings	Loss
244 lb.	25 lb.	37 lb.	2.0 lb.
75.0%	7.7%	11.3%	6.0%
44.9%S.	40.5%S.	38.1%S.	
		52.0%A.	

* 26.5 per cent. means that 26.5 per cent. by weight of the original material was saved here.

FIG. 182. MINE REFUSE FROM RAVENSCROFT OPERATION OF BON AIR COAL AND IRON CORPORATION

mines of the Bon Air Coal and Iron Corporation, of Bon Air, Tenn. The possibilities of utilization of coal pyrite on a large scale for the manufacture of sulphuric acid made it desirable to conduct tests on this material to learn if mechanical crushing and washing would produce a high-grade commercial pyrite free from coal and other impurities and with possibly clean coal as a byproduct. The report following gives an outline of the final tests, together with a flowsheet outlining a possible method of mechanically treating these materials.

This lot, about 500 lb. of crude coal pyrite marked from the Eastland mine, consisted of lenses of pyrite up to 10 in. in width and 4 in. in thickness, together with considerable adhering coal. To the eye, about 50 per cent. of the lumps by volume was pyrite and the remainder was coal.

Preliminary tests showed that the clean pyrite in the material was high grade, and that crushing to about 1-in. size would produce a clean pyrite concentrate, and consequently fairly clean

coal as a byproduct. During crushing, a comparatively small amount of pyrite fines was produced, and therefore the largest sizes were the richest in pyrite. In other words, this coal pyrite, unlike the usual pyrite mineral, is stony and amorphous in structure and does not slime on crushing. This very important point made it possible to recover most of the pyrite by jigging alone, and the concentrating table was necessary only in treating the recrushed middlings. Even this product might be fed into the jig and saved as a hutch product, providing the capacity of the jig was ample.

The accompanying quantity flow-sheet (Fig. 181) shows the results of the final test run on the pyrite from the Eastland mine. Four hundred and twenty-two pounds were crushed to ¾ in. size in a gyratory crusher followed by rolls. This was jigged in a two-compartment Hartz jig with ¼ in. screen beds. The coarse concentrates were saved as a screen-bed product and the fine con-

RESUME OF RUN OF EASTLAND MINE, BON AIR COAL AND IRON CORPORATION
Total, 422 lb.; 32.7 per cent. sulphur

Product	Concentrates Analysis Sulphur,		Middlings Analysis Sulphur,		Tailings Coal Analysis		Loss
	Weight	Per Cent.	Weight	Per Cent.	Weight	Per Cent.	
First bed concentrates	156	43.1	..	....	..	.....	....
First hutch concentrates	24	44.0	..	....	..	.....	....
Second bed middlings (see table products)	...	....	..	....	..	.....	....
Second hutch	...	....	26	36.1	..	.....	....
Jig tailings	...	....	..	....	63	5.3S. 19.8A.	....
Table concentrates	85	41.6	..	...	..	.....	....
Table middlings	...	....	8	30.1	..	.....	....
Table tailings	...	....	..	....	19	12.3S. 32.1A.	....
Jig loss	...	....	..	....	..	.....	34
Table loss	...	....	..	....	..	.....	7
Totals	265	42.7	34	34.7	82	6.9S. 22.6A.	41

Practically 265 lb. of commercial pyrite was recovered, or 62.8 per cent. of the total material treated. On further treatment, the 34 lb. of middlings could be expected to yield 25 lb. of commercial pyrite, making a total recovery of 290 lb. of pyrite or 68.7 per cent. The coal tailings were 82 lb. or 19.4 per cent. The treatment loss was 41 lb., or 9.7 per cent.

TABLE 53

centrates were saved as a hutch product. The second screen-bed product contained some coal adhering to the pyrite and was a true middling product. It was therefore crushed through a ¼ in. screen and treated on a Butchart concentrating table. The table cleaned this product and produced a high-grade concentrate.

The crude coal pyrite from the Ravenscroft mine was of about the same physical appearance as the material from the Eastland mine. Some of the lenses, however, were of rather light weight and had a peculiar gray color. To the eye it appeared about 75 per cent. pyrite by volume while the remainder was adhering coal. This material was tested in a preliminary way and the tests indicated that the same treatment could be used as with the material from the Eastland mine. This is a point of importance, because in any concentrating plant it would allow indiscriminate mixing of the material from the various mines before treatment. On crushing, the crude pyrite produced only a small percentage of fines, and it appeared that in regular practice, crushing to 1 in. round hole size would be sufficient before attempting concentration.

CHAPTER XXXII

WATER SYSTEM

In a washery the jigs use most of the water required, but depending upon the different installations water is also used for spraying, in dust collectors, and in sludge treatment. In a general way it can be assumed that about from three to six tons of water are required for each ton of coal, or from 725 to 1450 gal. of water must be put in circulation for each ton of coal treated. But the amount of water actually necessary varies a great deal with the character of the raw coal, the number of sizes made and the expected output. The last point demands especial consideration.

The water consumption increases immensely if the washery is overloaded. In such cases the water must assume part of the work which the overloaded jigs cannot perform to the required degree of exactness. Table 54 shows what quantities of water

Size of Coal	Percentage	Amount in Tons	Water Required in Gallons per Ton of Coal	Water Required in Gallons per Day
Lump coal	20	600	....	....
Nut coal, ⅜ to 3 in...	35	1,050	965	1,013,250
Fine coal, ⅛ to ⅜ in...	30	900	1,440	1,296,000
Sludge, 0 to ⅛ in.....	15	450	240	108,000
Fresh water for spraying nut coal.......	...	....	24	25,200
Total	100	3,000	....	2,442,450

TABLE 54

are required in a washery. We assume a mine hoisting 3000 tons of coal per day and that 80 per cent. of this amount will be handled in the washery. The table shows the different sizes of the washed coal made and the required quantities of water. If the washery is designed for a daily capacity of 2400 tons—

that is, for a 12-hour shift—the hourly water requirements are 203,537 gal. or 1017 gal. of water per ton of coal.

It thus becomes clear that only in extremely exceptional cases can the clarification and reuse of the wash water be neglected. Assuming the cost of water at only 0.005 of one cent per gallon (which means 20,000 gal. for $1), the water alone would cost 5.09c. per ton of coal and the daily expenditure for a washery with an output of 2400 tons of coal would be $122.16 for water alone. Therefore, every effort should be made to clarify and recirculate the water without appreciable wastage.

Water losses can be divided into unavoidable and avoidable ones. Unavoidable ones are brought about by evaporation and by a certain amount of water being carried away with the washed coal, the refuse and the sludge. These losses are increased by any necessity for rapid operation, which gives little time for drainage. Only in the bins has the coal time to lose some of the water. With the installation of mechanical dryers, however, this loss has been greatly diminished as most of the water adhering to the coal is returned to the system. But there still remains the loss of water caused by the moisture in the outgoing refuse and sludge.

The loss of water that drains out of the bins is avoidable through collecting it in gutters. Avoidable also are the losses caused by leaky tanks and sluice-ways. These losses increase with the age of the washery and can hardly be entirely eliminated. The use of steel, cast iron and concrete for tanks and sluiceways will cut down this loss considerably and will also make the whole plant a good deal cleaner. The idea that a washery must be sloppy is not only erroneous, but expensive.

The amount of the water losses varies widely with the construction of the washery, its age and the materials used in its construction. It is safe to assume such loss as amounting to from 8 to 10 per cent. of the total quantity used. This amount must be taken into consideration in figuring upon the necessary fresh-water supply. Whether these figures will be sufficient depends entirely upon the efficiency of the water-clarification plant.

If mine water which is acidulous or salty is used, greater quantities must be wasted so as not to increase the acidity of the water beyond a safe point. If concrete is largely used in the

construction of tanks and sluiceways, care must be taken to keep the acidity of the water within close limits, as acid water has a disastrous effect upon concrete structures.

In general the degree of water clarification desirable depends upon the proportionate cost of power and water, the possibility of clarifying the water and of allowing the dirty water to run away without damaging adjoining property or polluting streams.

For water circulation in the washery centrifugal pumps are almost universally used. The character of the water, the requirement of lifting large volumes of water under comparatively low heads and the floor space at disposal forbidding large pumprooms, render centrifugal pumps especially advisable. It must be emphasized also that the whole washer operation depends upon the uninterrupted service of the circulating pumps; therefore, it would be mistaken economy to leave a spare circulating pump out of the washery equipment merely on account of lack of convenient space or a shortage of money.

The fact that water clarification is the final process places the pump cistern at the lowest point of the washery. It is important to make the pump cistern big enough to take care of all the water in circulation when the pumps are shut down and, on the other hand, to give the pumps sufficient water from which to draw at the beginning of the operation. It has been found advisable to interpose between the circulating pump and the jigs a water tank or high-level reservoir for the purpose of supplying the jigs with water under constant pressure and at the same time to provide further storage space.

The power required for the circulating pumps varies considerably, depending upon the volume of water to be circulated and upon the difference in elevation between the pump cistern and the jig tanks. Approximately, it can be assumed that for a washer having a capacity of 100 tons per hour there are required 70 to 125 h.p.; for 150 tons per hour, 100 to 150 h.p.; for 200 tons per hour, 140 to 170 h.p.; for 250 tons per hour, 160 to 250 h.p. Besides the circulating pumps several other pumps are required to handle the sludge from the thickeners and the clear water and the sludge from the clearing basins. It is also advisable to install a high-pressure pump for fire protection and for the purpose of washing off the floors.

CHAPTER XXXIII

POWER

The amount of power required depends primarily upon the capacity of the washery. The following must be considered to determine the total amount of power required: The methods of operating the screens, the jigs, the dust collectors, the crushers, etc.; in short, all of the mechanically operated equipment. This in turn depends upon the character of the raw coal and its impurities. The power required for each piece of apparatus designed for a certain capacity and material is known; therefore, the summation of the power required for all the apparatus gives the total power necessary. To this total, however, must be added a certain percentage to take care of the power losses sustained in transmission.

Local conditions and arrangements of the machinery influence power consumption. To reduce the power requirements to a minimum it is desirable to either use the natural elevation or to raise the raw coal to such a height that the flow of the materials can be carried on by gravity alone or with the aid of sluicing water. In a level country there are some limitations to this ideal condition on account of the difficulty encountered in designing and operating heavy elevators of great capacity in an economical manner.

The power required per ton of coal treated will vary between considerable limits. Average values taken from existing installations are given as from 2 to 3 h.p. per ton of hourly capacity. Some modern installations, however, with a complete system of water clarification and sludge recovery, require as much as 5 h.p. per ton of hourly capacity.

From the foregoing discussion it can easily be seen that only after a careful examination of all the details will it be possible to decide upon a suitable general arrangement. Furthermore, the cost of power plays an important part in the proper selec-

tion of the machinery. A mine paying only ¾c. per kilowatt-hour can consider in the selection of the machinery other advantages than a mine paying 1½ cents.

Table 55 gives the average power required for the different pieces of apparatus used:

Description of Apparatus	Power Required for a Washery Having a Capacity per Hour of —Tons— 100	150	200
1. Dust collector in screen house......	5 to 18	6 to 18	7 to 18
2. Screens in tipple..................	6 to 15	8 to 25	15 to 40
3. Picking tables and loading booms....	10 to 15	10 to 25	15 to 30
4. Conveying rock and picked-out slate..	6 to 15	6 to 15	6 to 15
5. Conveyors from screen to fine coal bin	5 to 10	6 to 12	8 to 15
6. Crushers	80 to 120	100 to 160	150 to 200
7. Raw coal elevator..................	15 to 30	20 to 50	30 to 60
8. Conveyors for raw coal storage bin..	5 to 10	5 to 12	5 to 15
9. Magnetic separator	5 to 10	5 to 10	7 to 15
10. Preliminary screens	5 to 10	7 to 15	10 to 20
11. Dust collector	5 to 10	5 to 15	6 to 20
12. Coarse coal jigs...................	15 to 25	20 to 40	40 to 52
13. Coarse refuse elevators............	5 to 10	7 to 12	10 to 15
14. Rescreening of nut coal............	5 to 8	5 to 12	7 to 15
15. Conveying nut coal to storage bins...	5 to 6	5 to 8	6 to 10
16. Conveying middle products..........	5 to 6	5 to 8	6 to 10
17. Crushing middle products...........	10 to 30	20 to 40	30 to 60
18. Rewash jigs	5 to 10	10 to 15	15 to 20
19. Fine coal jigs.....................	10 to 15	15 to 20	20 to 30
20. Concentrating tables	7 to 12	10 to 15	15 to 20
21. Fine refuse elevators..............	2 to 5	3 to 6	5 to 8
22. Conveying fine coal to storage bins..	8 to 20	12 to 30	15 to 30
23. Drying of fine coal................	60 to 100	100 to 150	150 to 200
24. Sludge recovery	5 to 10	10 to 15	15 to 20
25. Water circulation	70 to 125	100 to 150	140 to 175

TABLE 55

CHAPTER XXXIV

ARRANGEMENT OF MOTORS AND DRIVES

In the earlier washeries frequently only one main-drive unit (usually a steam engine) was employed for the whole plant, or one engine drove the washery and another the screening plant. The power had to be transmitted from one point to all the different pieces of apparatus. This resulted in complicated systems of transmission machinery distributed over the entire plant. The disadvantages of this arrangement were well known, even at that time, but as long as only steam was available as the sole source of power, a decentralization of the power supply was out of the question on account of the great weight and large size of the steam engines.

The disadvantages of such a centralized power station are as follows: The great number of shafts, pulleys, belts, sprocket wheels, chains, sheaves, ropes and clutches makes the installation expensive in first cost as well as in cost of operation. The supervision of such a plant is difficult, costly and dangerous. It requires a large crew to attend to the lubrication and upkeep of all this complicated machinery. The loss of power caused by friction and inefficient transmission machinery is enormous. The swiftly moving belts, chains, ropes and shafting are a constant source of danger to the operator. The necessary safeguards are expensive and at best only a cumbersome makeshift.

It is consequently only quite natural that the direct electric-motor drive has been quickly adopted for coal washeries. This permits the installation of small independent drives, avoiding all cumbersome, expensive and dangerous transmission machinery. The small motors can easily be placed in almost any position without heavy or expensive foundations.

For centrifugal pumps and crushers the electric motor drive is especially well adapted. Electric drives permit the different units to be operated independently one from the other. They

can be stopped easily and quickly by throwing a switch, which enhances the safety of the operation. The control of all motors can be consolidated on a central switchboard, so that by using a remote-control system any unit can be started or stopped from a central point. Furthermore, cutout switches can be placed at convenient points throughout the plant, so that in case of danger it is not necessary to go to the motor or the central control board. Disastrous and costly wrecks can thereby be avoided.

The starting apparatus of the different machines forming one unit can be connected in such a way that it will be impossible to start one machine before the following one has been put in operation or, vice versa, to stop a machine before the preceding one has been shut down. This, in case of crushers, elevators and conveyors will avoid choking up any piece of apparatus and spilling coal. It is easy to make the operation of an electrically driven plant foolproof by taking the successive starting of the separate pieces of machinery out of the hands of the machine operator.

The starting apparatus should be provided with an overload circuit breaker so that in case of a jam in the machinery, wrecks or burnouts of the motors will be avoided. No-voltage releases ought to be installed also, so that in case of a sudden failure of the power supply the motors will not start when the power comes on again. It should be possible to lock the starting apparatus, to provide a safeguard for the men repairing the machinery.

Slow-speed motors are in most cases advisable on account of the extra expense and increased loss of power caused by speed-reducing gears. Constant-speed motors with a good starting torque should be employed, except for elevator and jig drives where a variation of speed is sometimes required. Washed coal and refuse elevator drives should be designed to permit the reducing of the elevator speed for short periods.

The only disadvantage of electric-motor drive encountered in actual operation arises from the inability to change the speed within the limits sometimes required in the operation of a washery. It is necessary to slow down the greater part of the machinery at certain intervals to permit a careful and thorough inspection. For this purpose the speed of the machinery should be reduced at least to 25 per cent. of the normal working speed.

With steam engines as main-drive units the speed of the machinery can be reduced to almost any degree and the starting and stopping can be accomplished without exposing the machinery to sudden stresses and shocks.

The question remains, How far should decentralization be carried? To install a separate motor for each piece of apparatus would require an undesirable number of small motors, which would increase the cost of installation out of all proportion to the advantages gained thereby. The whole electrical equipment would become complicated and the control unwieldy.

It will be far more advisable to combine the drives for a group of machinery, making thus one drive unit, if one motor can actuate it by means of simple, conveniently arranged transmission apparatus. This is especially the case with jig drives. Therefore, we must consider in the selection of a proper drive the following: The degree of decentralization depends upon the space at disposal. This sometimes requires a fixed arrangement of the machinery, regardless of the convenient arrangement of the drives. In some cases, however, it will be possible to consider the most convenient and economic drives, regardless of other requirements. Therefore, generally speaking, no special method of driving can be pronounced as the best. Each separate case demands its particular solution and the number of motors to be installed will vary from 6 to 37. In the simplest case the motors can be arranged into groups as follows: (1) Raw-coal elevator and preliminary screening; (2) all the jigs, the washed coal and refuse elevators; (3) sizing screens; (4) washed coal conveyors to the bins; (5) circulating pump; (6) sludge-handling and water clarification.

In the most complicated case, where the decentralization has been carried to extremes, we find the following: (1) Docking table; (2) coal conveyors to crusher; (3) feeders under unloading hopper; (4) cross conveyor from unloading hopper; (5) conveyor for foreign coal to crusher; (6 and 7) crushers; (8) conveyor to raw-coal storage bin; (9) reclaiming conveyor under storage bin; (10) conveyor to screen house; (11 and 12) sizing screens; (13, 14 and 15) conveyor for sized coal to equalizing bins; (16 and 17) jigs; (18 and 19) washed-coal elevator; (20) refuse elevator; (21, 22, 23 and 24) dryers; (25) washed-coal

conveyor; (26 and 27) circulating pumps; (28, 29 and 30) sludge pumps; (31, 32, 33, 34 and 35) thickeners; (36) concentrating tables; (37) laboratory crusher.

The horsepower of the foregoing 37 motors varies from 7½ to 250, and two voltages are used—that is, 440 and 2300—besides the lighting circuit of 110 volts.

CHAPTER XXXV

BUILDINGS AND STRUCTURES

Timber construction is rather antiquated and undesirable on account of the fire risk. Only in certain cases, where the acreage of the mine will not promise a long life will it be excusable to use timber in the construction of a washery. But even then the danger of fires must be considered. Such fires, even when the washery is fully insured, entail a lengthy interruption to oper-

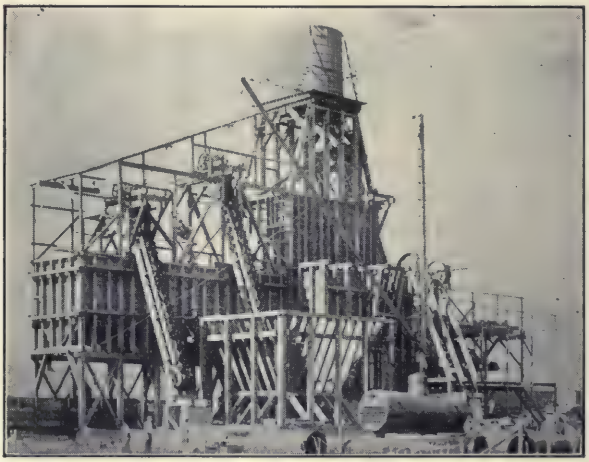


Fig. 183. Timber Work of Coal Washery in Course of Construction

ation and a consequent loss of profit, or even the loss of a desirable customer.

In addition to this, timber construction, on account of the larger size of timbers necessary, narrows down the space at disposal and the great number of joists, beams and braces interferes with the passageways and the convenient supervision of the plant. Reinforced concrete for the building proper is expensive and has the further disadvantage that changes and addi-

tions cannot be made except at great cost and under difficulties.

For tanks, sluiceways and bins, reinforced concrete is supreme. In connection with this it may be stated that concrete sluiceways ought always to be lined with glazed terra-cotta tile to resist abrasion. For the construction of the housing over the machinery, steel is the only feasible material. A steel structure makes a light, rigid and durable building, permitting the location of plenty of windows and ventilators. Daylight is the cheapest item we have at our disposal, and it should be used freely. Ma-

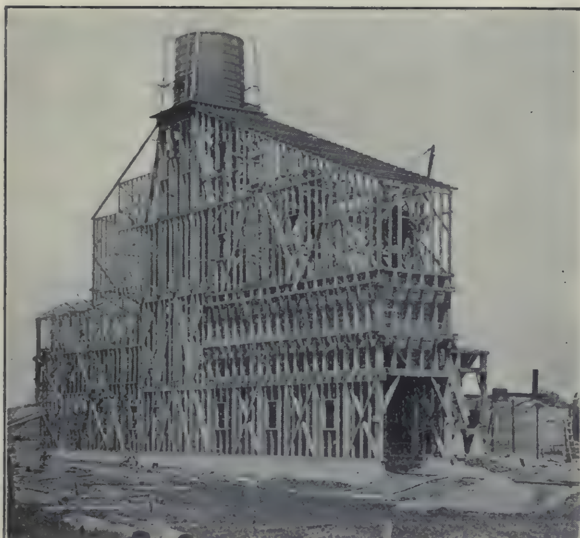


Fig. 184. Photograph Showing Studdings for Side Walls of Washery

chinery supports can be arranged easily, and floor beams, stairways and walks conveniently placed to provide accessibility to all parts without obstructing the view.

For the covering of the buildings we have a great variety of materials, so that the proper selection will depend upon the climate, the money available and the personal preference of the designer. Under ordinary conditions galvanized corrugated steel sheets are quite suitable for the sides of the buildings. If painted and kept in good repair, they will last a reasonable time; but even under the most favorable conditions the cost of upkeep

is considerable, and they do not give sufficient protection in colder climates. The increased cost for heating may easily overbalance the cheapness of corrugated steel siding.

In a warm climate the sides can be arranged in sliding panels so as to give plenty of fresh air in the summertime. In colder climates, and for durability, concrete stucco work on an expanded metal base is advisable. This offers good protection against the weather and does not require painting or frequent repairs. It ought to last as long as the steel framework.

Roofs can also be covered with galvanized corrugated steel

Fig. 185. Washery Built Entirely of Timber

sheets, but asbestos cement in the shape of shingles or corrugated sheets is far more advisable. Floors should be made of reinforced concrete with a non-dusting top dressing and arranged in such a way that they can be easily and thoroughly washed off. Stair treads should either be filled in with concrete or made of some non-slip material. The inside of the building, especially the under side of the roofs, should be painted in, say, a light gray color.

The idea that a washery must be a dark, sloppy place has long ago been exploded. A coal washery can be made just as clean and light as any other industrial building. Plenty of light not only means convenience but also safety. Dark corners are tabooed in modern construction. The ideal design should permit the unobstructed supervision of all machinery from one point.

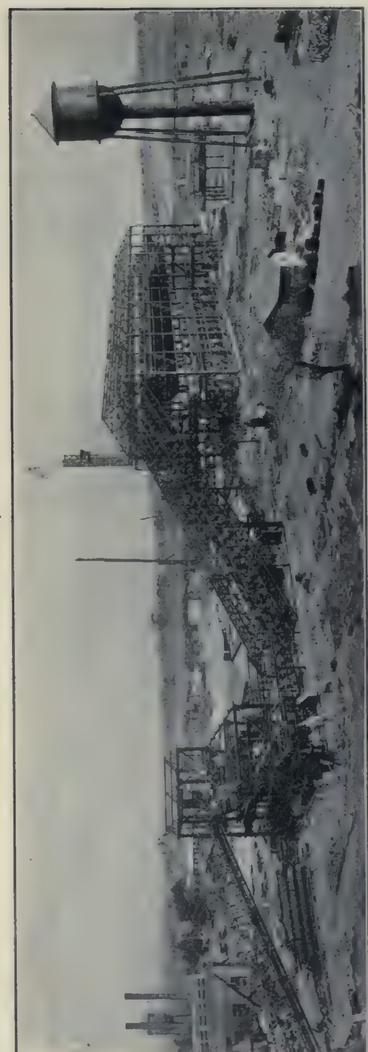


Fig. 186. Modern Coal Washery Built of Steel and Concrete

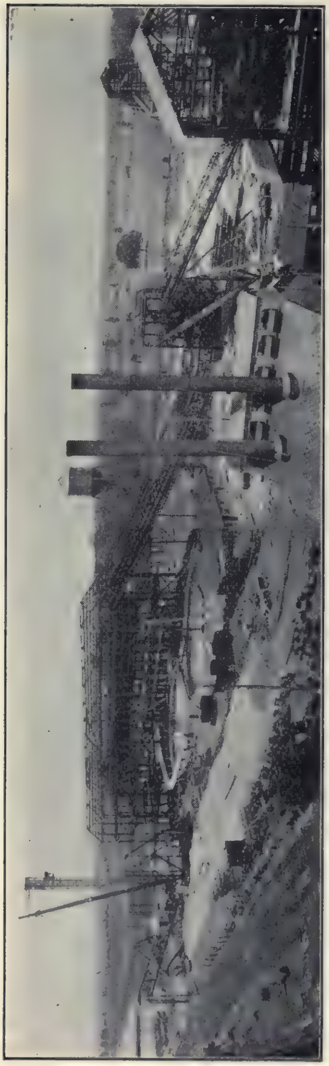


Fig. 187. Modern Washery Built of Steel and Concrete. Concrete Dor Thickener Tanks Shown in Foreground

The main requirements to be considered in the design of a washery building may be condensed as follows: The building must give sufficient protection against the inclemencies of the weather; all vibration must be taken care of; all the machinery must be in full and unobstructed view from preferably one but in any case as few points as possible; all machinery must be safely, fully and easily accessible; artificial lighting should only be required during the night-time; no dark corners should be permitted; changes in the arrangement of the machinery must be easily accomplished.

Figs. 183 and 184 show the framework of a coal washery built entirely of timber. Fig. 185 illustrates the same washery completed. Figs. 186 and 187 are photographs of a modern washery under construction.

CHAPTER XXXVI

COST OF WASHING COAL

A guarantee for a certain amount of ash in the washed coal is only to be considered if at the same time a certain yield is also guaranteed. The cost of operation is an important factor. An indisputable guarantee should read: With x cents cost of operation per ton of such and such a coal handled we guarantee an output of y per cent. with z per cent. of ash in the washed product.

To check these figures it is necessary to take average samples of the different products and analyze them. Therefore, a laboratory is a necessary appendage to a washery. Daily samples ought to be taken, the ash and sulphur contents determined, also the percentage of "sink" in the washed coal and the percentage of "float" in the refuse. These results ought to be posted on the jig floor so that the jig runner can see what he is doing. To do this with any degree of accuracy it is imperative to install automatic samplers, described on pages 130 to 132.

The cost of operation depends upon the character of the raw coal, just as the yield and the percentage of ash and sulphur in the washed coal depend upon it. But the cost of operation is furthermore influenced by the arrangement of the washery and the supply and application of power and water. General conditions only can here be considered, as each separate case must be handled in a different way and individually. Weekly or at least monthly cost sheets on a per unit (ton of input) basis are of great value, especially as the comparatively simple operation of a washery permits an easy and correct subdivision of the cost for all separate operations. By carefully studying and comparing the figures obtained valuable information can be gained which will be a guide in making changes in the method of operation. It is therefore judicious to arrange the cost sheets according to

the different units of operation, so that we get the cost of each step of the process separately.

The cost of operation must be divided into fixed charges, operating expenses and the cost of special work. It is only natural to keep the cost of installation as low as possible. This effort in economy is limited, however, by the necessity of keeping the cost of operation and that of repairs as low as possible. If one operator can be saved by a certain increase in the cost of installation, this increase will be justified if it is lower than the capitalized wages of the operator. This is because it is desirable to become as far as possible independent of the imperfection of human labor.

The regular cost of operation includes wages, cost of power, water, light and lubricants. In regard to the cost of power and water we must consider that they depend in many cases on the more or less perfect operation and efficiency of the machinery. An increase in the cost of power and water, if it brings about a cleaner washed coal, is commendable if this increase remains below the possible better price obtained for the cleaner product.

The cost of special work includes wages and cost of material for repairs and renewals. While the above-named cost can at least partly be predetermined, that of repairs appears only in the course of time, after the washers have been in operation. To arrive at the exact cost of repairs is difficult. Depending upon the time used for repairs, the absolute expense is much higher than the cost of labor and material expended, because we must take into account the loss incurred through the interruption of operation of the washery, which may in some cases reflect even upon the operation of the mine.

The breaking down of an elevator, with the bins full and no spare parts on hand, may be given as an example. Therefore, all important machinery ought to be fully guaranteed by responsible manufacturers as a safeguard against interruption of operation. This may, however, bring about an increase in the cost of installation, influenced by the heavier and better-constructed machinery.

The cost of washing coal shows just as many variations as everything else connected with a washery. The following figures (Table 56), however, can be given as an approximate guide:

	Cost per Ton of Raw Coal Minimum, Cents	Maximum, Cents
Amortization and interest of capital invested........	3	5
Cost of operation (wages, power, water, light, stores)	8	20
Cost of repairs................................	2	5
Total	13	30

TABLE 56

To the foregoing figures, however, must be added the cost of shrinkage, which will depend upon the amount of impurities in the raw coal and the degree of cleaning—that is, upon the yield. I have operated different washers that made from 10 per cent. to 33 per cent. refuse.

L. A. O. Gabany gives the cost of washing in Alabama as follows:

STEIN JIGS IN THE FIRST YEAR OF INSTALLATION; ELEVEN JIGS AND THREE OPERATORS FOR THREE CONSECUTIVE DAYS

Run of Mine Ash per cent.	Run of Mine Sulphur per cent.	Washed Coal Ash per cent.	Washed Coal Sulphur per cent.	Refuse Content Per Cent. Good Coal	Refuse Content Per Cent. Bone Coal	Output for Three Days Tons	Cost per Ton of Coal Cents	Analysis of Coke Ash per cent.	Analysis of Coke Sulphur per cent.
12.91	1.44	5.0	0.86	3.24	2.62	1,646	5.32	8.96	0.96

3 jig tenders at $3 each..............................	$ 9.00
3 assistant tenders at $2 each........................	6.00
3 oilers at $1 each...................................	3.00
Oil	2.10
Water	9.05
Fuel	6.55
Repairs	2.50
	$38.20

2.32 cents per ton
3.00 depreciation

5.32 cents total, irrespective of the good coal lost in 10.4 per cent. refuse which equals 10 tons of good coal in three days.

TABLE 57

F. C. Lincoln, in Bulletin No. 69 of the Engineering Experiment Station of the University of Illinois, tabulated the cost of washeries and of washing for Illinois washeries as shown in Table 59. In explanation of this table Mr. Lincoln says:

STEIN JIGS FOR THE FIFTH YEAR FROM INSTALLATION; ELEVEN JIGS AND THREE OPERATORS FOR TWO DAYS

Run of Mine Ash per cent.	Run of Mine Sulphur per cent.	Washed Coal Ash per cent.	Washed Coal Sulphur per cent.	Refuse Content Per Cent. Good Coal	Refuse Content Per Cent. Bone Coal	Output for Two Days Tons	Cost per Ton of Coal Cents	Analysis of Coke Ash per cent.	Analysis of Coke Sulphur per cent.
13.20	1.32	8.15	0.86	24.9	16.2	1,046	5.88	11.22	0.98

2 jig tenders at $3 each	$ 6.00
2 assistant tenders at $2 each	4.00
2 oilers at $1 each	2.00
Oil	1.40
Water	6.06
Fuel	4.27
Repairs	6.40
	$30.13

2.88 cents per ton
3.00 depreciation

5.88 cents total, irrespective of good coal lost in 10.7 per cent. refuse which equals 34.83 tons of good coal in two days.

TABLE 58

"The costs of power, labor, supplies, repairs and renewals per ton of raw coal washed, as reported by fifteen washeries, varied from 3 to 18 cents, with an average of about 10½ cents. In obtaining this average, depreciation was included in one instance but this is probably more than offset by omission of costs of power from reported general washing costs which are likely to be made when mine and washery are operated with the same power plant, so it is believed that this average is low rather than high. The cost of building fifteen washeries with a combined capacity of 1740 tons raw coal per hour was $572,000. At the same rate the 33 operating commercial washeries of Illinois with their combined hourly tonnage of 3555 would have cost $1,169,000. These figures do not represent the total investment in washeries, as they do not include cost of land for washery, reservoirs and refuse dump sites. Costs of individual washeries could not be included in Table 59 without violating the confidences of some of the operators, but costs per ton rated capacity are given. These costs are for washeries with hourly tonnages ranging from 25 to 280 and averaging 116, and show costs of from $130 to $583 per ton capacity per hour, with an average of $351. The costs of individual washeries, while showing considerable irregularity, still vary in a general way with size and type. The average cost per ton capacity per hour of seven washeries with capacities of 100 tons and under was $448, while eight washeries with capacities in excess of 100 tons averaged $266. The average cost of three Lührig jig washeries was $393 per ton capacity per hour, of six Stewart jig washeries

The Elmore washery shown in Fig. 202 did cost $677 per ton rated hourly capacity.

Costs of Washeries and of Washing

Cost of Washery per Ton Rated Capacity per Hour (Dollars)	Cost of Washing per Ton Raw Coal Washed: Power (Cents)	Labor (Cents)	Supplies, Repairs and Renewals (Cents)	Depreciation (Cents)	Insurance (Cents)
280	1.69	7.02	4.60		
375	2.50	7.50	2.19		1.20
583					
	2.016	13.290	2.671	2.754	0.599
		3.3	0.8	3.4	
294	0.5		10.6	(5–7½%)	
130			6.00		
			15.24		
268			8.60		
563			5.00–10.00		
277			9.50		
400			10.80		
217			3.00	(5%)	
583			16.60		
380					
280			3.00		
280					
350			14.00		
Average 351			10.42		

Table 59

CHAPTER XXXVII

GENERAL ARRANGEMENT OF WASHERIES AND GRAPHICAL ILLUSTRATION OF THE PROCESS

The design of a coal washery is a complicated problem on account of the extremely numerous factors influencing the arrangement. This becomes still more complicated when the separate requirements become contradictory. We have in the foregoing chapters fully discussed which requirements should be considered and which should be given preference. Drawings for a washery can be made in different ways, depending upon the purpose for which they are intended.

If it is only necessary to get an idea of the methods used and the succession of the operations, plain flow sheets will suffice. Flow sheets are of great help for preliminary estimates. They are indispensable when the operations become complicated, in order to comprehend quickly the correlation of the different processes. In Figs. 189 and 190 two flow sheets are shown. One for a fuel-coal washery taking 3 in. screenings from a distant mine and the other for a coking-coal washery directly connected with the mine. The flow sheet for the fuel-coal washery illustrates the operation of the washery shown in Fig. 197.

In Fig. 188 a different kind and more elaborate type of flow sheet is shown for a washery making five sizes of fuel coal and a coking coal at the same time. In this flow sheet the different pieces of machinery are shown in outline and the separate units are shown in nearly the same juxtaposition as they are placed in the washery.

In studying this flow sheet we find: That the dry screened-off dust can be mixed directly with the washed fine coal. The middle products from the coarse coal jigs can be carried, according to their composition, either back to the coarse coal jigs or to the rewash jigs. In the latter case only boiler-house coal can be made. If the amount of fine coal, screened out, is not suffi-

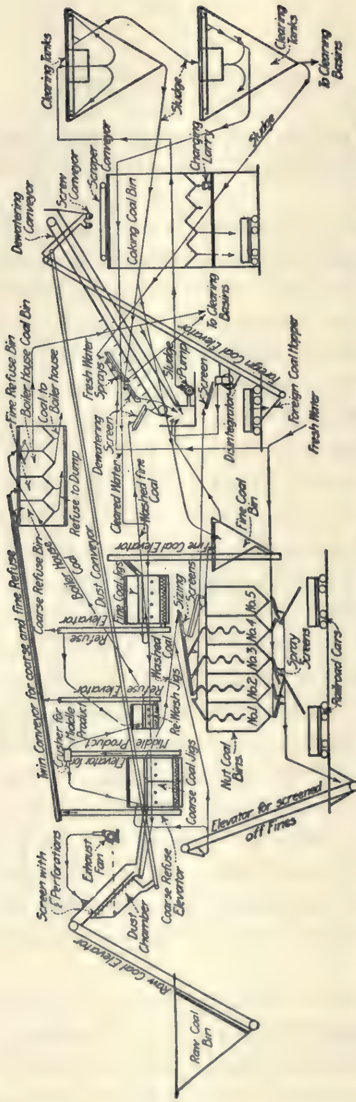


Fig. 188. Flow Sheet for Coal Washery. Showing the Different Apparatus in Outlines

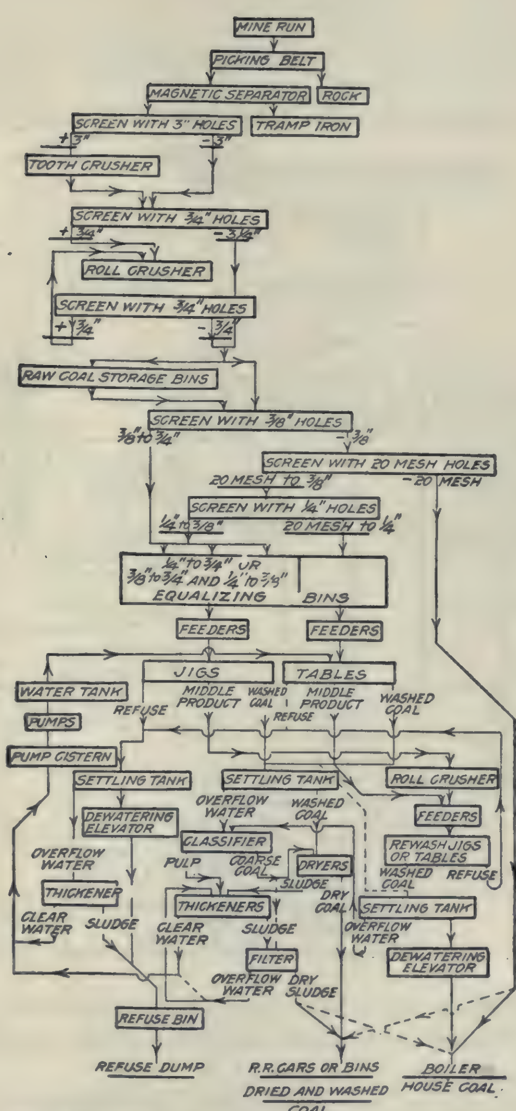


Fig. 189. Flow Sheet for Coking Coal Washery

cient for the supply of the coke ovens, some of the nut coal can be crushed and delivered in connection with some foreign fine coal to the coking coal bins.

In the sludge cistern the following materials are collected: (a) The drained-off water from the fine coal; (b) the sludge from the clearing tanks after being filtered through the screens;

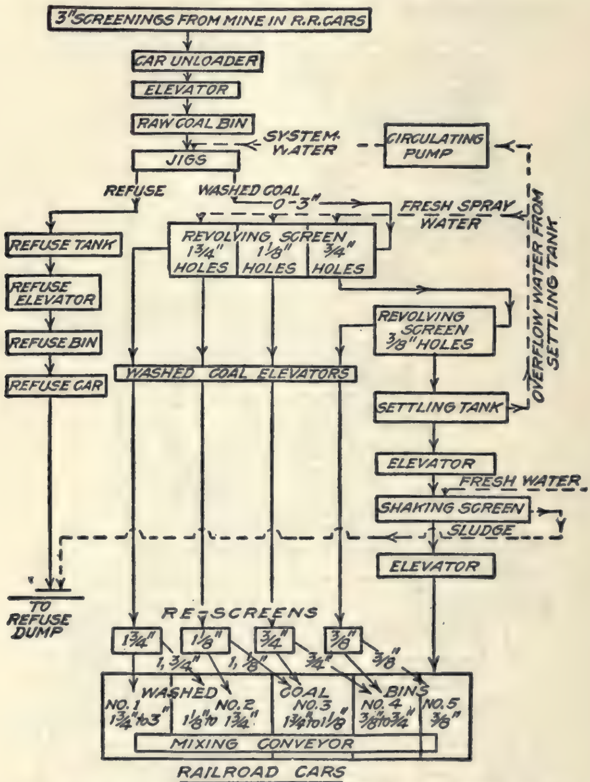


Fig. 190. Flow Sheet for Fuel Coal Washery Shown in Fig. 197

(c) the overflow water from the fine coal bin; (d) the water drained off from the crushed nut coal; (e) the overflow water from the boiler house coal storage bin.

The screw conveyors over the coking coal bins are used to mix the fine coal, the dry dust and the crushed nut coal with the foreign fine coal. The first clearing tank produces sludge, which

can be used, but the second tank only during continuous operation, as after a shut-down the fireclay settles out on the bottom and must be removed to the clearing basins.

The flow sheet, Fig. 191, shows the progress of operation for

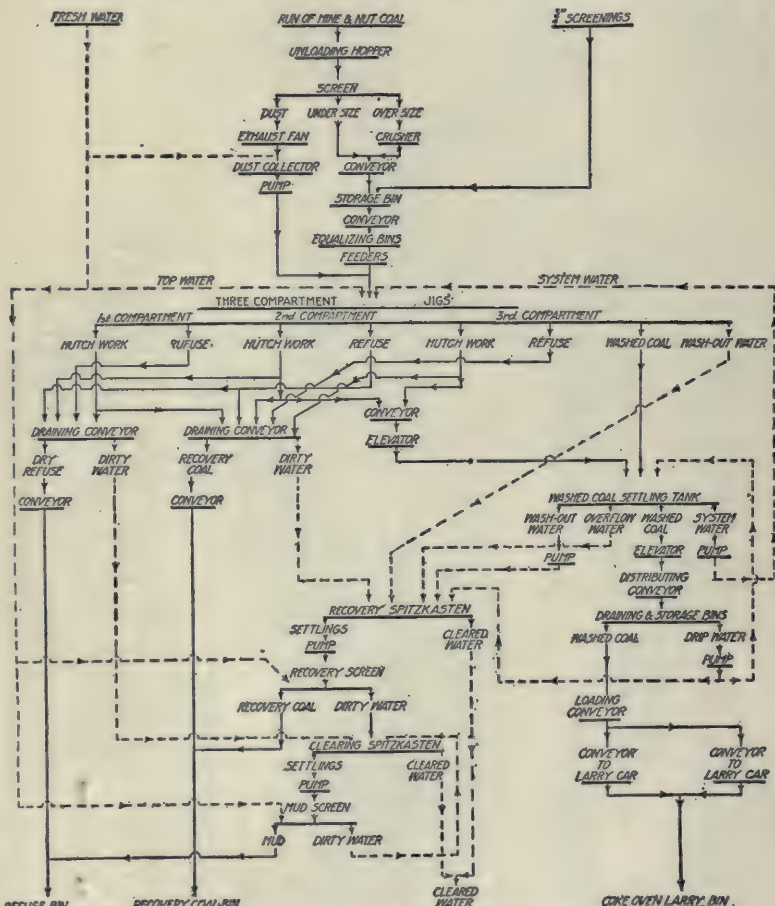


Fig. 191. Flow Sheet for Washery Illustrated in Figs. 198 and 199

a coking-coal washery arranged according to Figs. 198 and 199. This washery is arranged to take coal from several mines. Run-of-mine is received in railroad cars and dumped in a track hopper. From this hopper the coal is passed over a screen. The

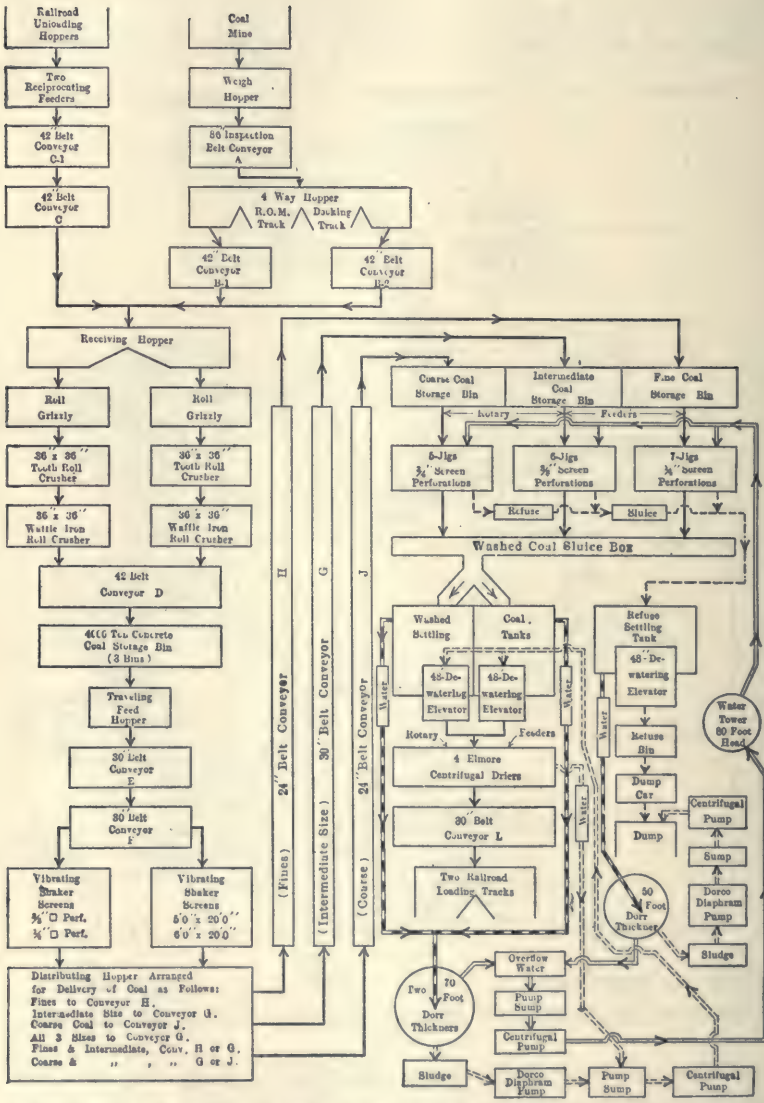
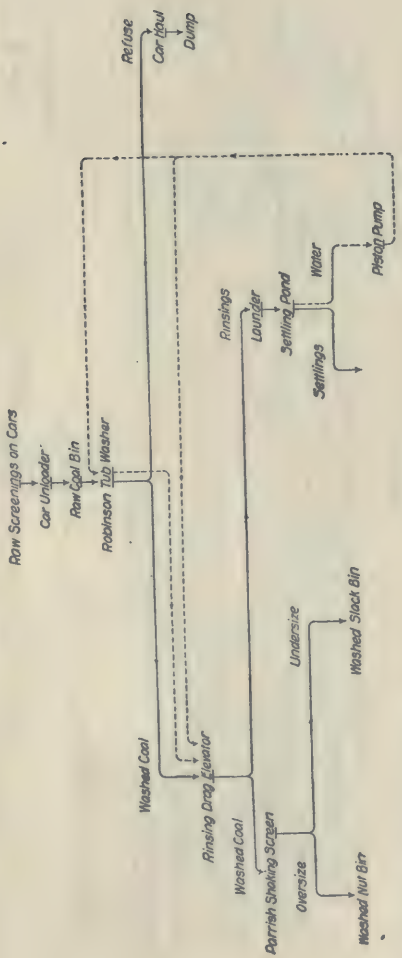


Fig. 192. Flow Sheet for Coking Coal Washery Illustrated in Fig. 200



Note - Course of coal shown in full lines. Course of water in broken lines.

Fig. 193. Flow Sheet for Robinson-Ramsay Washery

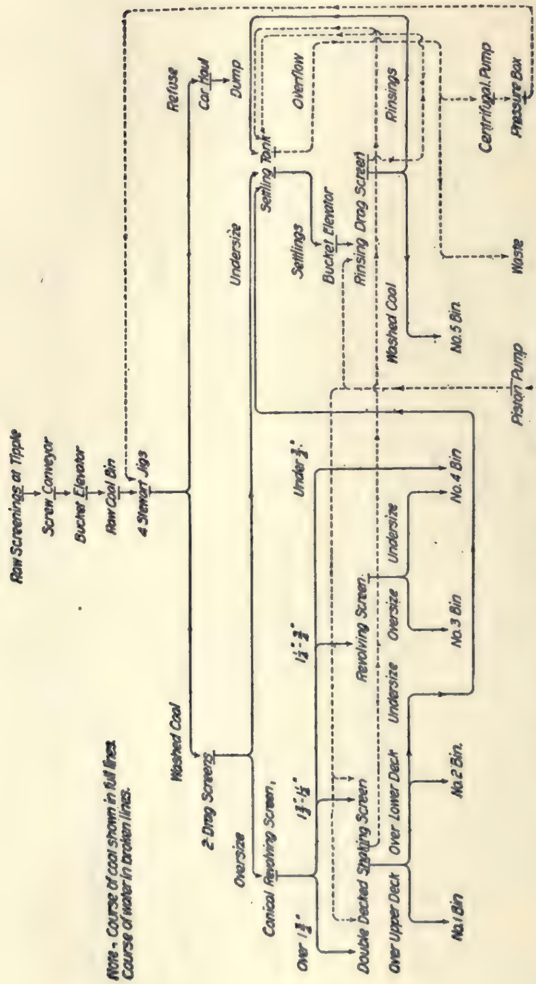


Fig. 194. Flow Sheet for Stewart Washery

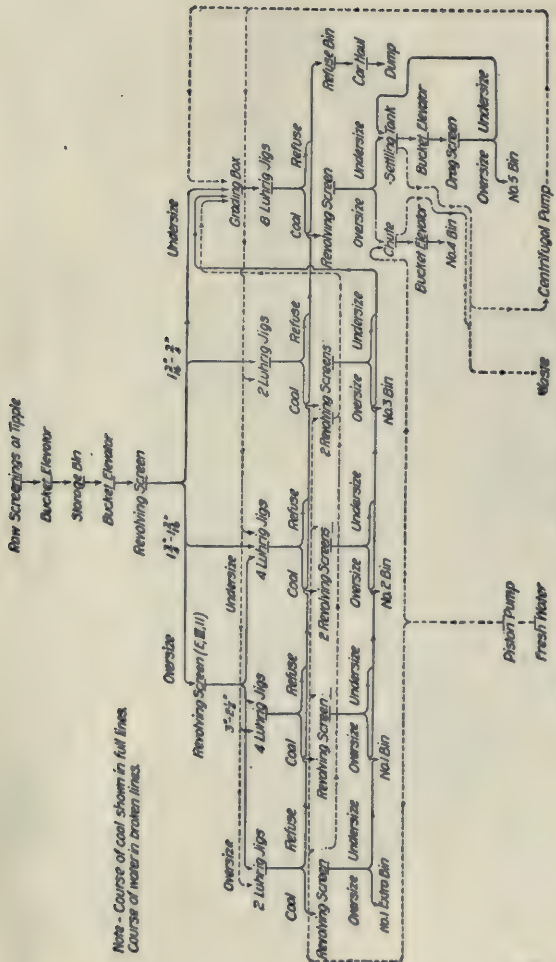


Fig. 195. Flow Sheet for Lührig Washery

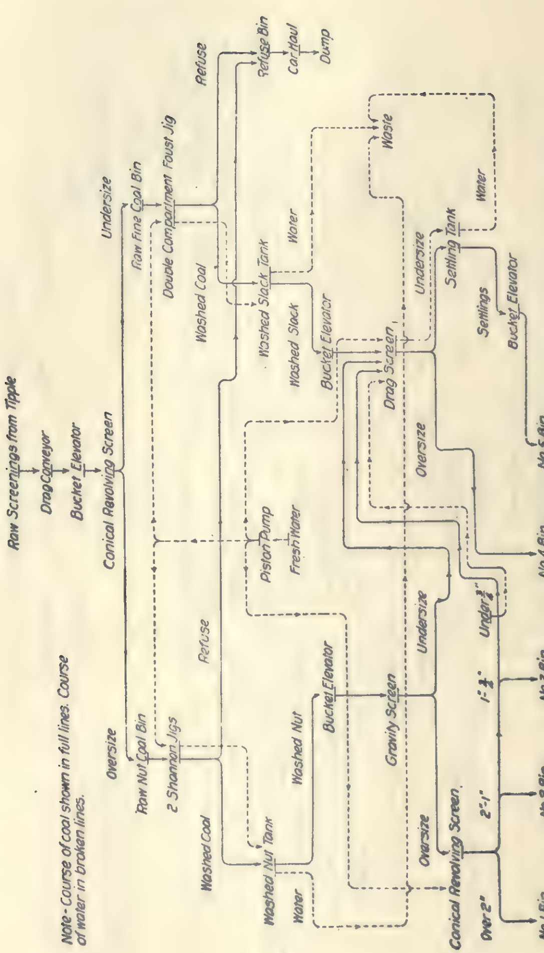


Fig. 196. Flow Sheet for Fuel Coal Washery Employing Shannon Jig for Coarse Coal and Faust Jigs for Fine Coal

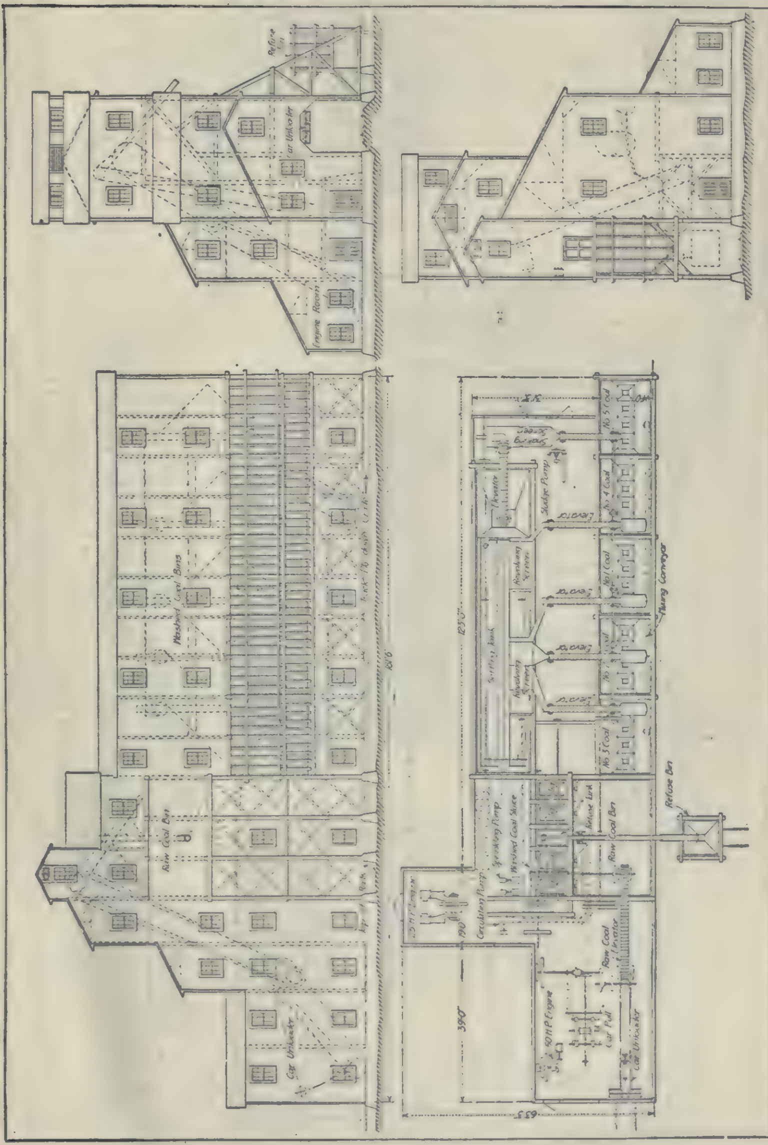


Fig. 197. Fuel Coal Washery Making Five Sizes of Washed Coal

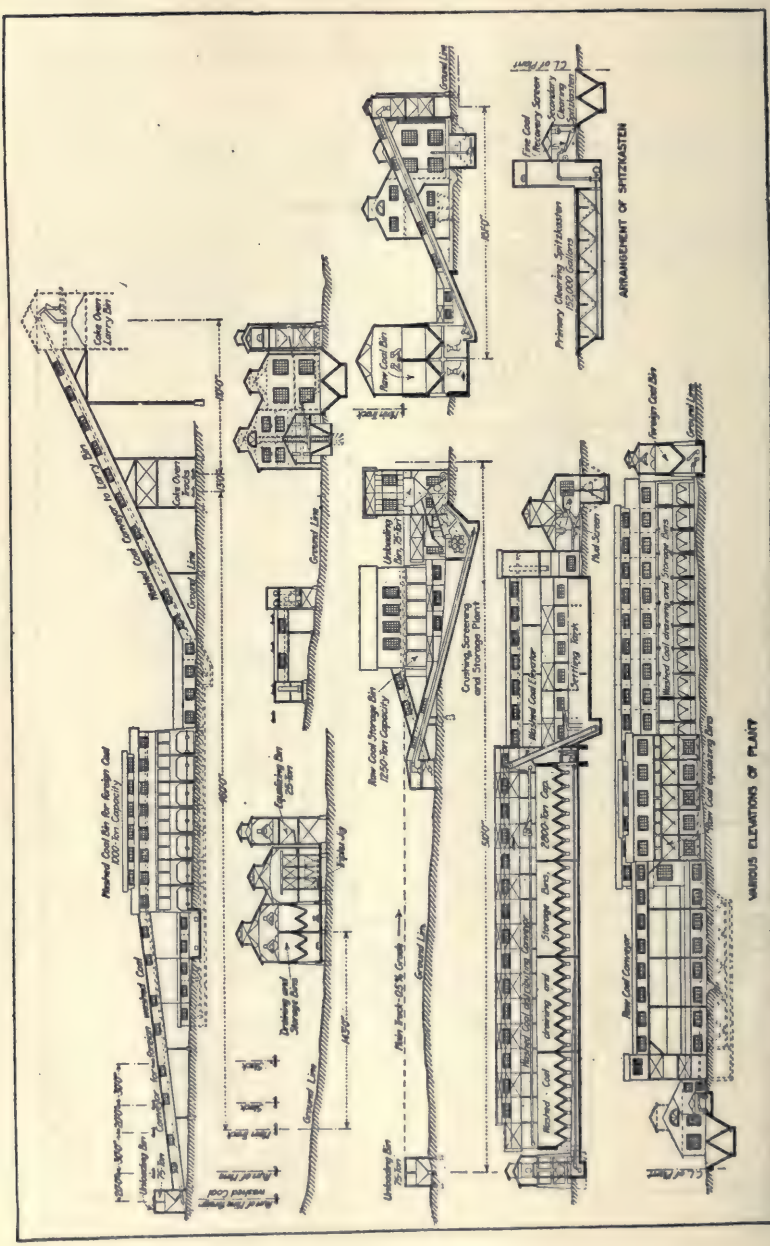


Fig. 198. Elevations of Coking Coal Washery

oversize from the screen is crushed and the crushed and screened coal is put into a storage bin, which also receives the screenings from other mines. From the storage bin the coal is conveyed to the equalizing bin, located in the rear of the jigs. From here feeders carry the coal to the jigs. At the feeders the dust col-

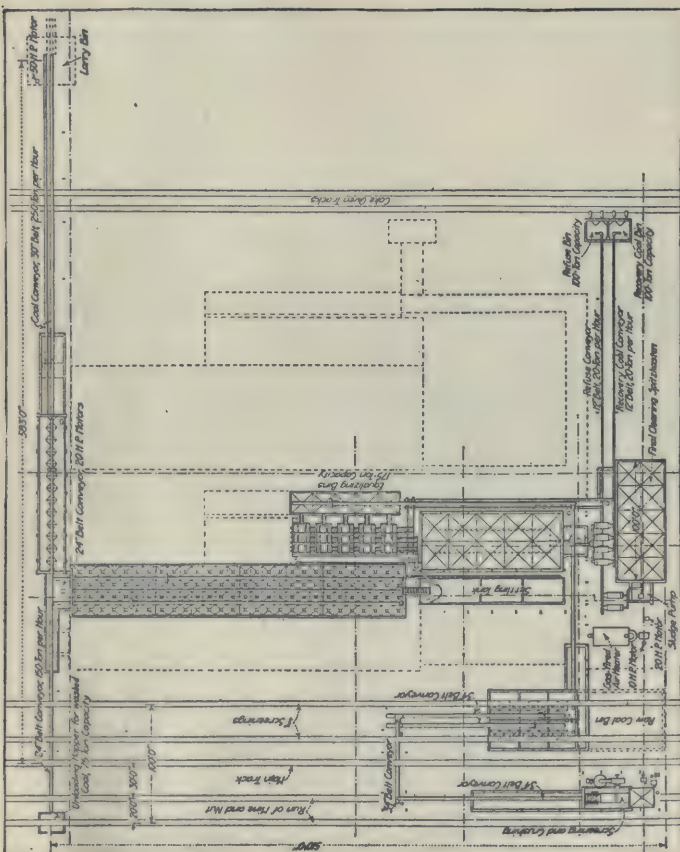


Fig. 199. Plan of Coking Coal Washery

lected at the screen house is mixed in with the coal. The jigs are three-compartment machines, making three products, which, depending on their composition, can be treated in different ways.

From the washed-coal settling tank the coal is conveyed to a series of draining bins to be dewatered, and from these bins it is

conveyed to the coke-oven larry bins and thence to the coke ovens. The refuse is deposited in a refuse bin and carried away in railroad cars to a dump. The recovery coal, after passing over a draining or dewatering conveyor, is stored in a bin.

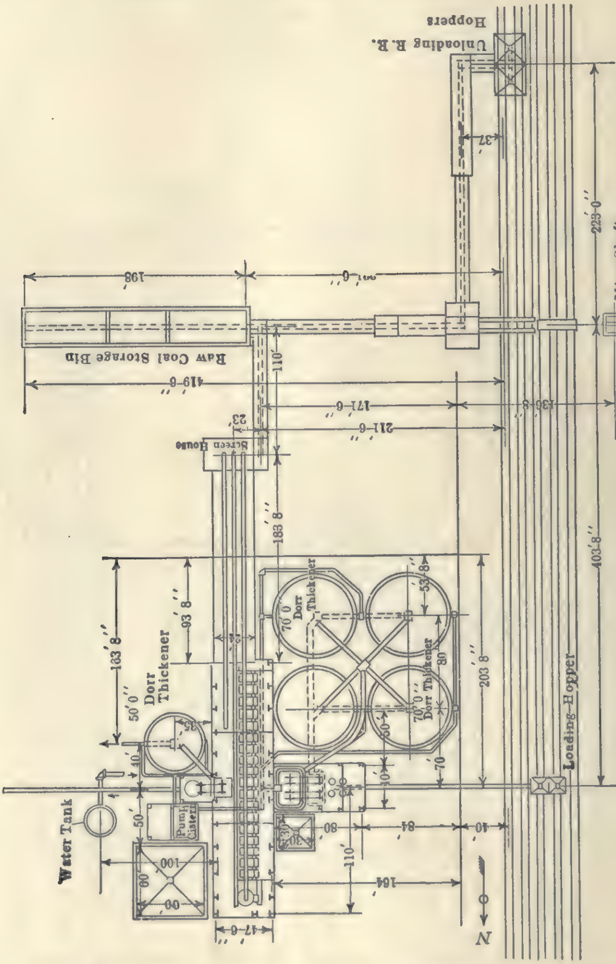


Fig. 200. Plan of Modern Coking Coal Washery

The dirty water from the recovery coal draining conveyor, the overflow water from the washed-coal settling tank, the wash-out water from the jig tanks and the washed-coal settling tank, and the drip water from the draining bins is collected in a recovery

spitzkasten. The settlings from this *spitzkasten* are further treated on a recovery screen and the resulting recovery coal mixed in with that coming from the jigs. The cleared water is collected in a cistern for reuse. The drip water from the draining bins can also be conveyed back to the washed-coal settling tank.

The dirty water from the refuse draining conveyor and the recovery screen is treated in a clearing *spitzkasten.* The settlings pass over a mud screen. The resulting mud is mixed with the outgoing refuse and the dirty water from the screens carried back to the clearing *spitzkasten.* The cleared water from

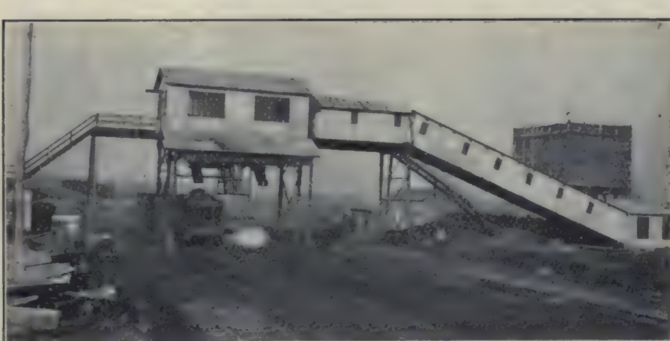


Fig. 201. Loading Arrangement of Washery Shown in Fig. 200

the *spitzkasten* flows to the clear-water cistern. The circulating pump takes the water from the washed-coal settling tank and puts it back under the jigs. Fresh water is supplied to the dust collector, the jigs, the recovery and the mud screens.

The general arrangement of a fuel-coal washery is shown in Fig. 197. Flow-sheets, Figs. 193 to 196, were supplied by the Engineering Experiment Station of the University of Illinois from Bulletin No. 69, "Coal Washing in Illinois," by F. C. Lincoln.

Fig. 200 shows the general arrangement of a modern coking coal washery, taking either run of mine direct from the tipple or foreign coal by means of an unloading pit. This washery is equipped with an elaborate system for clarifying the water and recovering the sludge. The washed coal is dewatered in Elmore centrifugal dryers and loaded directly into railroad cars. This

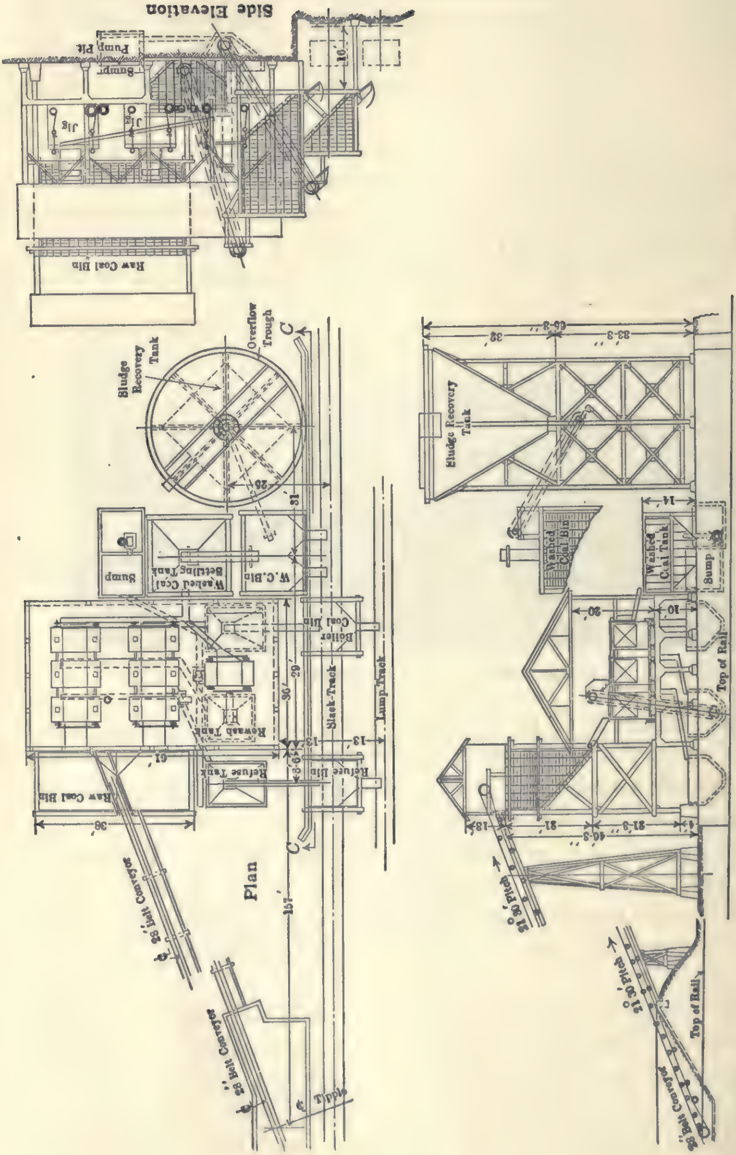


Fig. 202. Coking Coal Washery Equipped with Two Three-Compartment "Elmore" Jigs and One Rewash Jig

method avoids the construction of a costly washed coal storage bin. Fig. 201 shows the loading arrangement, which consists only of two chutes, one over each of the two loading tracks.

Fig. 192 gives the flow sheet for this washery, and Figs. 186 and 187 show this washery in course of construction.

Fig. 202 illustrates the general lay-out of a coking coal washery taking coal direct from the mine by means of a belt conveyor. This washery is equipped with two three-compartment "Elmore" jigs and one rewash jig. The sludge recovery is carried on in an elevated conical tank.

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